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Dr. Eric V. McDonald and Mr. Todd Caldwell

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This study quantified physical and chemical characteristics of dust derived from soils sampled in Iraq. Recognizing that weapons jamming could be related to physical and chemical properties of dust, the Desert Research Institute (DRI) was commissioned by the Army Research Office to undertake an analysis of a limited number of Iraqi dust samples collected during the period 27 March – 8 April 2004 by an onsite geologist of the U.S. Army Corps of Engineers. The purpose of this study is to describe the physical and chemical properties of sampled Iraqi dust, to analyze how this dust reacts with gun lubricants used in Iraq, and to develop recommendations for additional testing that would contribute to resolving the gun-jamming problem experienced by U.S. soldiers. Given the importance of Iraqi dust in its potential to impact military equipment and operations, desert environmental parameters are critical to design tests that reflect real-world conditions—especially conditions most likely to compromise use of critical equipment in harsh desert environments. Analytical results describing physical and chemical properties of the Iraqi dust samples provide scientific guidance for the next steps in solving dust-related problems.

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Enclosure 1

Geochemical and Physical Characteristics of Iraqi Dust and Soil Samples

Photographs by J. Kelley ERDC-GSL

Final Project Report

Prepared for:

Yuma Proving Ground
Natural Environments Test Office

Prepared by:

Dr. Eric McDonald
Mr. Todd Caldwell

Desert Research Institute
Division of Earth and Ecosystem Sciences

and

Center for Arid Lands Environmental Management

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ABBREVIATIONS LIST

Acronyms

ASTM	American Society for Testing and Materials
Av	Surface vesicular horizon
B	Bulk samples
Btk	Subsurface soil horizon, zone of accumulation
CHN	Elemental Carbon, Hydrogen and Nitrogen analysis
CLP	Cleaner, Lubricant, and Preservative
DRI	Desert Research Institute
EC	Electrical Conductivity
ERDC	Engineer Research and Development Center
GSL	Geotechnical and Structures Laboratory
GZ	Green Zone
ICDD PDF	International Centre for Diffraction Data, Powder Diffraction File
ICP-MS	Inductively Coupled Plasma - Mass Spectrometry
LOI	Loss on ignition
LPSA	Laser particle-size analysis
MDI	Materials Data, Inc
NA	Not analyzed
NBMG	Nevada Bureau of Mines and Geology
ND	No data
NTC	National Training Center, Ft. Irwin, CA
PC	Personal Computer
PSDA	Particle-Size-Distribution Analysis
RI	Refractive Index
SI	Southern Iraq
STHD	Strike Hold-1
TV	Tactical Vehicle
USMA	United States Military Academy
XRD	X-ray Diffraction
XRF	X-ray Fluorescence
YPG	Yuma Proving Ground

Minerals and Chemicals

Al_2O_3	Aluminum oxide
$CaSO_4 \bullet 0.5H_20$	Bassanite
C	Carbon
CO_3^{2-}	Carbonate
CO_2	Carbon dioxide
$CaCl_2$	Calcium chloride
$CaCO_3$	Calcite
Cl^-	Chloride
$Ca,Mg\ (CO_3)_2$	Dolomite
$CaSO_4.2H_2O$	Gypsum
NaCl	Halite

Fe_2O_3	Iron oxide
$Si_4Al_4O_{10}(OH)_8$	Kaolinite
$(Al, Fe^{2+}, Mg)_4Si_8O_{20}(OH)_4$	Montmorillonite
NO_3^-	Nitrate
P_2O_5	Phosphorus oxide
$NaAlSi_3O_8$	Plagioclase
$(Mg,Al)_5(Si,Al)_8O_{20}(OH)_2 \cdot 8H_2O)$	Palygorskite
$KAlSi_3O_8$	Potassium feldspar
K_2O	Potassium oxide
SiO_2	Quartz
$(Li,Mg)_4Si_8O_{20}(OH)_4$	Saponite
Na_2O	Sodium oxide
SO_4^{2-}	Sulfate
TiO_2	Titanium oxide

Units

°C	Celsius
dS/m	Decisiemens per meter
g	gram
mg kg^{-1}	milligrams of constituent per kg of soil (= ppm)
µm	micron, micrometer, 1 µm = 0.001 mm
ppm	parts per million

Particle Size Classes

Gravel	>2000 µm particle diameter
Fine-earth fraction	<2000 µm particle diameter
Sand (sand-sized)	62.5 to 2000 µm particle diameter
Silt (silt-sized)	3-62.5 µm particle diameter
Clay (clay-sized)	<3 µm particle diameter

EXECUTIVE SUMMARY

For the U.S. Army to operate successfully on a global scale, current and future troops as well as their equipment must be capable of accomplishing any mission in all possible environments: cold or hot, wet or dry, and every possible combination of terrain. This requirement challenges the Army's equipment, people, and training programs. To prepare for a full spectrum of operations, the Army develops and tests its equipment under extreme environmental conditions to ensure that America's soldiers have the best that science and technology can provide. Further, units conduct training in a realistic manner and in environments that simulate various natural settings. Finally, the Army must collect and analyze environmental data necessary to successfully plan for contingencies worldwide.

A particular and critical issue has evolved from U.S. combat experience in Iraq. Troops have reported that their individual combat weapons (M4 and M16 rifles) were jamming and failing to fire dependably. No specific causes were identified, but anecdotal information suggested that the problem was related to high levels of dust in the area combined with the properties of standard Army cleaner, lubricant, and preservative (CLP). Some troops had acquired commercially available gun lubricants that were reported to work better. An Army study (King et al., 2004) identified that dusts present in the world's deserts varies greatly in physical and chemical properties, variables that have significant implications for military operations. This recent experience and knowledge has reinforced the importance of understanding the impacts of desert environments on military operations, especially in critical areas such as proper functioning of weapons.

Recognizing that weapons jamming could be related to physical and chemical properties of dust, the Desert Research Institute (DRI) was commissioned by the Army to undertake an analysis of a limited number of Iraqi dust samples collected during the period 27 March – 8 April 2004 by an onsite geologist of the U.S. Army Corps of Engineers. The purpose of this study is to describe the physical and chemical properties of sampled Iraqi dust, to analyze how this dust reacts with gun lubricants used in Iraq, and to develop recommendations for additional testing that would contribute to solving the gun-jamming problem for U.S. soldiers. This first-phase study is intended to provide a scientific basis for addressing dust-related aspects of the problem, not to provide a final solution.

Fifteen Iraqi dust samples were collected in total. Of these, nine were bulk surface soils collected at a variety of locations and were intended to capture some of the variability in dust sources based on the geology and geomorphology of the region. To evaluate potential differences between parent soils and resultant dust, six additional samples were taken inside tactical vehicles where weapons were stored or transported. All samples were analyzed to determine particle size, chemical composition, and reactivity of soil or dust components. Eight of the samples were tested to determine reactivity with three types of gun lubricants, including government stock CLP and two commercial products that troops found to work better than standard CLP.

Analytical results describing physical and chemical properties of the Iraqi dust samples provide scientific guidance for the next steps in solving dust-related problems. The most critical findings from this study are:

- Soils and dust collected from areas of military activity in Iraq differ significantly from the material used in chamber-testing procedures for weapons and are unlike natural geologic materials to which weapons are exposed during most training environments in the U.S.
- The concentration of reactive chemicals, primarily salts and carbonates, is high in all Iraqi dust and soil samples and extremely high in many. Several of these reactive chemical components have the potential to corrode metal parts.
- The average particle size of dust encountered in military operations in arid regions is much smaller than laboratory-generated quartz surrogate dust used in sand-and-dust chamber testing of weapons. Army experience has clearly shown that natural dusts have a significant impact on weapons operation and other mechanical equipment.
- Laboratory testing has shown that three gun lubricants react with Iraqi dust, forming aggregates that increase the average size of particles in the sample. The extent of the reaction varies among dust samples with different chemical compositions and grain sizes. In general, dusts higher in salts and carbonates, and with smaller particles, are most reactive when mixed with the lubricants.
- The average particle size of dust taken from vehicles in Iraq was significantly smaller than the particle size of bulk soil samples. Further, the samples from vehicles had a higher concentration of reactive carbonates and sulfates. This reinforces that current chamber test methodology misrepresents real-world conditions.

Identifying the complete cause of gun-jamming problems experienced in Iraq must include testing with actual dust, or the equivalent, from the areas where the problems occurred. Differences in bulk soil samples compared with dust found in military vehicles operating in Iraq verify that operational considerations must be included in designing tests to evaluate and resolve this issue. Moving vehicles, and the weapons carried therein, act as natural dust traps for the smallest, and most potentially reactive, dust particles.

Given the importance of Iraqi dust in its potential to impact military equipment and operations, desert environmental parameters are critical to design tests that reflect real-world conditions—especially conditions most likely to compromise use of critical equipment in harsh desert environments. Previous work by King et al. (1999, 2004) demonstrated that each type of equipment test has a unique set of environmental conditions that are critical to the success of that test. Further analyses of the chemical properties of Iraqi dust are recommended to evaluate potential for corrosion and related impacts to military equipment.

This study quantified physical and chemical characteristics of dust derived from soils sampled in Iraq. This dust was found to be highly variable based on its origin and significantly different from the quartz materials used for standard chamber dust tests of military equipment. Further, the high concentrations of reactive chemicals and high volumes of fine clay materials were observed to react with chemicals found in gun lubricants.

INTRODUCTION

This report focuses on the primary chemical, physical, and mineralogical characteristics of soil and dust samples collected in Iraq during March and April 2004 and an analysis of how this dust reacts with gun lubricants currently in use in Iraq. A principal reason for this analysis is that troops in Iraq have reported that their individual combat weapons (M4 and M16 rifles) were jamming and failing to fire dependably. No specific causes were identified, but anecdotal information suggested that the problem was related to the high levels of dust in the area and the properties of Army standard gun lubricants. Some troops had been acquiring commercially available gun lubricants that were reported to work better.

Penetration of dust into weapons has a high potential to result in weapon malfunctions. Desert dust commonly contains an abundance of small particles <100 µm (1 µm = 0.001 mm diameter) that are susceptible to airborne deposition on and within weapons. Moreover, desert dust commonly contains several potentially chemically reactive constituents, especially organic matter, soluble salts (e.g., NaCl, $CaSO_4$), and carbonate ($CaCO_3$, $MgCO_3$). Dust composition, therefore, may provide several means for infiltrating weapons and adhering to weapon parts, resulting in increased resistance and/or binding of moving parts.

Previous sand-and-dust chamber testing of the M16 generally involved exposure of the weapon to dust composed of pure quartz sand that had been finely ground to include silt-sized particles (~2–62 µm diameters). Chemical constituents common to desert dust were not likely present during test procedures designed to evaluate the weapon's susceptibility to dusty conditions. Moreover, desert dust from Iraq has not been fully characterized previously to determine if the dust may be a source of physical or chemical constituents that could be a potential source of weapon jams.

The possibility that dust may be negatively impacting military equipment has reinforced the importance of understanding the impacts of desert environments on military operations. The nearly ubiquitous presence of dust is a fundamental characteristic of the world's deserts and is therefore likely to impact military operations, especially the functionality of weapons and equipment (King et al., 2004).

The objectives of this report are to provide a scientific analysis of sediment, soil, and dust samples recently collected from Iraq. Specific objectives include:

(1) Identification of key geochemical and physical attributes of sampled Iraqi dust
(2) Characterization of Iraqi soils and sediment that may be environmental sources of dust
(3) Characterization of the dust that accumulates within tactical vehicles in Iraq
(4) Establishment of potential for interaction between military-grade weapon lubricants and Iraqi soil and dust properties

The report is not intended to provide the final solution but to provide a scientific basis for addressing dust-related aspects of the problem and to suggest future directions for additional testing that will contribute to solving gun malfunctions.

Background: Desert Dust

Desert dust, generally regarded as small aerosolic particles and sediment deflated from desert surfaces, is a ubiquitous feature of the world's deserts. Dust is injected into the atmosphere by entrainment processes that can be natural (e.g., wind erosion of soils and sediments) or anthropogenic (e.g., vehicular movement, construction activities). Areas of bare, loose, and mobile sediment containing substantial amounts of sand and silt provide the most favorable surfaces for dust production. Natural environments that provide important sources of dust include flood deposits, soils (especially soils with sparse vegetation cover), ephemeral washes and riverbeds, eolian sediments (e.g., dunes), and terminal depressions where episodic ponding occurs. Anthropogenic environments that are important sources of dust include unpaved roads, agricultural fields, and construction sites.

Dust particle size depends in part on the distance from the dust source. Larger particles (~100–1000 μm) tend to settle near (i.e., within a few kilometers) of dust source areas. These particles travel primarily by saltation with transport primarily lasting minutes to a few days and occurring only when wind velocity exceeds thresholds required for entrainment. By comparison, smaller particles (<100 μm) can remain in suspension for many days and can be transported 10s to 100s of kilometers from source areas (Pye, 1987).

Particle distribution of airborne dust samples taken adjacent to dust courses at the U.S. Army Yuma Proving Ground during vehicle testing and within vehicles indicates that more than 75% of the particles range in size from 10 to 30 μm with fines in the 0.5 to 2.0 μm range. This source also reports the upper limits of dust particles sent airborne by tire-equipped vehicles in the range of 74 to 78 μm, which is near the lower limit of particle sizes used for dust-chamber testing.

Desert dust commonly contains a wide variety of chemical constituents including organic matter, carbonate, and soluble salts (e.g., NaCl, $CaSO_4$). Dust chemical composition will depend on chemical composition of sediments in the source area and will vary with distance from the source due to changes in particle-size distribution (i.e., dust size decreases with increasing distance from the source area).

Research Design

Sampling strategy: A sampling strategy was developed in January 2004 (Appendix A) and forwarded to the U.S. Army Engineer Research and Development Center Geotechnical and Structures Laboratory (ERDC-GSL) to serve as a sampling guide for Army personnel in Iraq. The objective was to collect a range of samples that would provide initial information about the source, geochemistry, and physical character of aerosolic dust that may impact military equipment. Three levels of samples were identified in this strategy:

1. *Bulk samples - samples collected from soils or sediments exposed at the surface that could contribute to dust emission.* Sample locations were sought in environments commonly associated with dust emission including soils, river basins, eolian deposits, and playas. These environments were selected to replicate some of the variability in dust sources based on regional geology and geomorphology.

2. *Tactical vehicle samples - samples from the interior or exterior of tactical vehicles operating in Iraq.* These samples were intended to provide two types of important information. First, dust that has accumulated in tactical vehicles reflects the character of aerosolic particles where military weapons are stored or transported. Second, vehicles provide a moving dust trap assimilating dust from a potentially wide geographic area. Samples collected from tactical vehicles are often easier to collect and may provide a useful proxy for common dust sources and types found within a given operational area. It should be noted that samples collected from tactical vehicles operating in Iraq may contain dust and sediment acquired prior to service there; however, the amount of this sediment is likely to be low if the vehicles were either occasionally cleaned in Iraq or have traveled extensively in Iraq.
3. *Gun lubricating oil - samples of oil and dust from jammed weapons.* Samples of gun lubricants collected from malfunctioning weapons would provide information about the presence or absence of dust in jammed weapons and the character of any dust present. Samples of gun lubricants from weapons that had malfunctioned were not available for collection and are not included in the analysis reported here. As an alternative, fresh gun lubricants were obtained for laboratory testing in combination with bulk and tactical vehicle dust samples.

Analysis: Laboratory characterization included a broad variety of chemical and physical analyses to determine major physical, chemical, and mineralogical constituents that comprise the dust samples. The objectives were to identify properties of the dust with the potential to interfere with military equipment operation and to provide primary information about the general nature of dust in Iraq.

Iraqi Dust Working Group

Analysis of dust characterization data included frequent discussions among personnel (Table 1) from DRI, Yuma Proving Ground (YPG), United States Military Academy (USMA), Army Research Office (ARO) and ERDC-GSL. This review included evaluation of the environmental setting of collected samples; laboratory methods used; results; general relevance to military operations; and consideration of the need for additional sampling, analysis, and evaluation. The working group also provided important comments on drafts of this report.

Table 1. Iraqi dust working group

Dr. Eric McDonald	Desert Research Institute, Earth and Ecosystem Sciences
Mr. Todd Caldwell	Desert Research Institute, Earth and Ecosystem Sciences
Dr. Tom Bullard	Desert Research Institute, Earth and Ecosystem Sciences
Dr. Russell Harmon	Environmental Services Division, Army Research Office
Mr. Graham Stullenbarger	U.S. Army Yuma Proving Ground-Natural Environments Test Office
Mr. Larry Havrilo	U.S. Army Yuma Proving Ground-Natural Environments Test Office
Mr. Dave Pond	U.S. Army Yuma Proving Ground-Yuma Test Center
Mr. Byron R. Cooper	U.S. Army Yuma Proving Ground-Yuma Test Center
Lt. Col. Dan Gilewitch, Ph.D.	United States Military Academy-West Point
Col. Chris King, Ph.D.	United States Military Academy-West Point
Dr. Lillian Wakeley	Engineer Research and Development Center Geotechnical and Structures Laboratory
Ms. Julie Kelley	Engineer Research and Development Center Geotechnical and Structures Laboratory

SAMPLE INFORMATION AND ANALYTICAL METHODS

Sample Type, Location, and Environmental Characteristics

Iraq samples: Fifteen dust samples were collected from Iraq in March and April 2004 by a research geologist with the ERDC-GSL (Kelley, 2004; Appendix B). General information regarding environmental factors (i.e., geomorphic setting, exposure to dust sources) is summarized from the report and provided in Table 2.

Nine bulk and six tactical vehicle samples were collected in Iraq in the general vicinity of Baghdad (GZ) and Basrah (SI). All samples were taken from tactical vehicles or from the shallow surface in regional soil settings. Nine large bulk soil samples (>1000 g each) were collected near Baghdad and Basrah (Table 2, Figure 1). Surface soil samples were collected with a plastic spoon and placed in liter-sized, zip-lock plastic bags. These samples are identified as bulk samples (abbreviated as B) in the report.

Six smaller dust samples (<50 g each) were collected from tactical vehicles. The samples were collected from select interior and exterior surfaces with a metal spoon or a clean toothbrush and placed in hard plastic vials (Table 2). These samples are identified as tactical vehicle samples (abbreviated as TV) in the report.

Table 2. List of samples collected from Iraq.

DRI ID	Sample ID	Field ID	Collected	Environment Notes
Bulk Samples				
04-1555	B1-GZ	River Bottom	3/27/04	Tigris River, flood slack-water sediments, Green Zone
04-1562	B6-SI	Floodplain and River Bottom	4/7/04	Shatt Al Arab River, intertidal area
04-1563	B7-SI	Regional Soil	4/7/04	Southern Iraq, petrocalcic layer, gravel surface lag
04-1564	B8-SI	Regional Soil	4/7/04	Southern Iraq, petrocalcic layer, gravel surface lag
04-1565	B9-SI	Floodplain and River Bottom	4/7/04	Southern Iraq, floodplain/river bottom, crust with silt/evaorites
04-1566	B10-SI	Playa	4/7/04	Southern Iraq, playa sediments
04-1567	B11-SI	Eolian	4/7/04	Southern Iraq, active sand dunes
07-1568	B14-SI	Regional soil	4/7/04	Fluvial terrace/floodplain, Shatt Al Arab River
04-1569	B15-SI	Lake Basin	4/8/04	Basrah International Airport, dessicated marsh
Tactical Vehicle Samples				
04-1556	TV2-GZ	Tactical Vehicle – Humvee	4/5/04	Primarily Green Zone travel, interior and wheel well
04-1557	TV3-GZ	Tactical Vehicle – Humvee	4/5/04	Daily travel outside of Green Zone, vehicle interior
04-1558	TV4-GZ	Tactical Vehicle – Humvee	4/5/04	Frequent travel outside of Green Zone, wheel wells
04-1559	TV5-GZ	Tactical Vehicle – Humvee	4/5/04	Frequent travel outside of Green Zone, wheel wells
04-1560	TV12- SI	Tactical Vehicle – Humvee	4/7/04	Southern Iraq, wheel well, no info on use
04-1561	TV13-SI	Tactical Vehicle – Truck	4/7/04	Southern Iraq, wheel well and door, no info on use

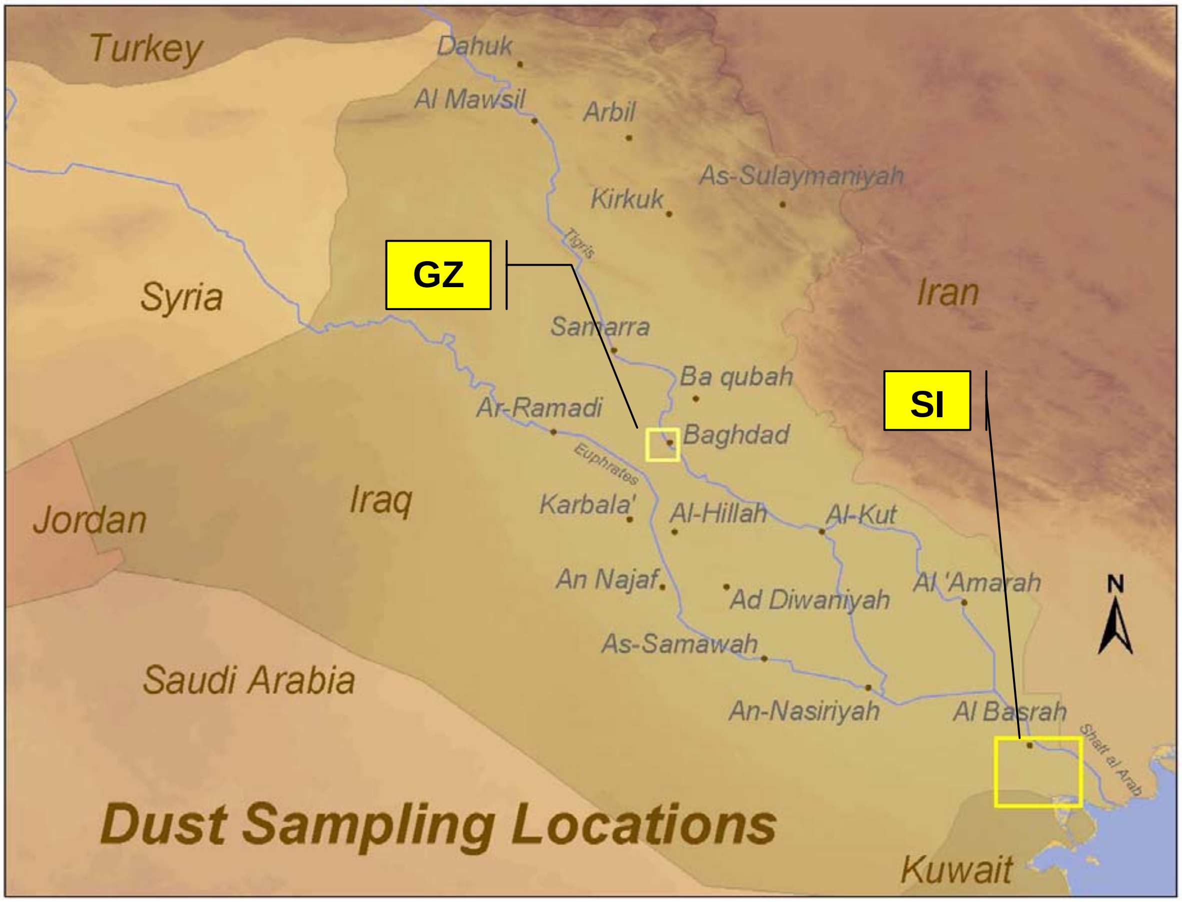

Figure 1. Sample locations within the Green Zone (GZ) and southern Iraq (SI), from Kelly, 2004 (Appendix B)

DRI laboratory test samples: Three samples that are frequently used by the DRI Soil Characterization and Quaternary Pedology Laboratory as an internal analytical standard were included in this study. A sample of pure milled garnet was used to provide (1) verification of the laser analysis technique for particle-size determination and (2) information about dust sample reaction to gun lubricants. Two soil samples, Yolo silt loam (California) and Warden silt loam (Washington state), also were included. Characteristics of these samples provide further information about laboratory accuracy and response of samples to exposure to gun lubricants.

Yuma Proving Ground soil: Two soil samples from the Yuma Proving Ground were used to evaluate particle-size distribution results. These samples consist of a surface soil horizon and a subsoil horizon. The samples were collected from a desert bajada near one of the primary YPG desert test courses (Middle East Test Course).

Gun lubricants: Three gun lubricants were used in our analysis. Ten gallons of MILSPEC CLP (Royal AR-70-94; CDS Inc.; Conroe, Texas) were obtained from the U.S. Army National Training Center (NTC) at Ft. Irwin, California. Five gallons of Strike-Hold-1 were purchased from MPH System Specialties Inc. (300 Seaboard Avenue Suite B, Venice, Florida). Ten gallons of Militec-1 gun lubricant were donated to DRI by

Militec, Inc. (11828 Pika Drive, Waldorf, Maryland). All three lubricants also serve as gun cleaners. For simplicity, all three products will be described as gun oil or gun lubricants.

Laboratory Methods

All soils sampled in this investigation were analyzed primarily by the DRI Soil Characterization and Quaternary Pedology Laboratory. The Nevada Bureau of Mines and Geology (NBMG) and ALS Chemex (Vancouver, British Columbia) performed all X-ray fluorescence (XRF) and X-ray diffraction (XRD) analyses. Analytical procedures are summarized in Table 3, and a brief description of each method is presented below.

Table 3. Soil laboratory analytical procedures

Analysis	Analysis method	Reference:
Particle Size Distribution[1]	Saturn Digisizer Laser light scattering	Gee and Or, 2002
Carbon and Nitrogen[1]	Perkin-Elmer CHN analyzer	Nelson and Sommers, 1996
Calcium Carbonate[1]	Chittick apparatus	Dreimanis, 1962; Machette, 1986
Soil pH[1]	pH Meter	Thomas, 1996
Electrical Conductivity[1]	Conductivity Bridge	Rhoades, 1996
Soluble Anions[1, 2]	Dionex Ion Chromatograph, water extraction	Tabatabai and Frankenberger, 1996
X-ray Fluorescence[2, 3]	Philips PW1404 XRF spectrometer	Karathanasis and Hajek, 1996
X-ray Diffraction[2]	Philips automated XRD	Whittig, L.D., and W.R. Allardice. 1986

[1]Analysis performed at the DRI Soil Characterization Laboratory
[2]Analysis performed at the Nevada Bureau of Mines and Geology
[3]Subsequent analysis performed at ALS Chemex

Pretreatment: Soil samples were oven dried at 105°C for 24 hours, and the gravel fraction (>2000 µm) was removed by dry sieving using an ASTM No. 10 sieve. All laboratory analyses were performed on the fine-earth fraction (<2000 µm), which is the standard-size fraction used for soil and sediment analysis. The gravel fraction was not analyzed because the focus of this study was on the characteristics of dust-size material.

Particle-size analysis: Laboratory measurement of particle-size distribution or soil texture was determined using laser diffraction techniques (Gee and Or, 2002). The laser particle-size analysis (LPSA) procedure is used to determine the percentage of size-class fractions in soil or sediment samples. This innovative procedure allows highly detailed distributions to be generated both with very small sample amounts, and within aqueous and non-aqueous solutions. The general procedure is based on ASTM C 1070–01 to determine particle-size distribution analysis (PSDA) of aluminum and quartz powders by laser-light scatter (ASTM, 2000). Laser-light scattering is based on the Mie theory of light scattering by a spherical particle using the Micromeretics Saturn DigiSizer 5200®. The sample is internally dispersed using ultra-sonication in an aqueous medium of 0.005% surfactant (sodium metaphosphate) and circulated through the path of the laser-light beam.

As particles pass through the laser beam, the light scatters at angles inversely proportional to particle size and with intensity directly proportional to particle size. A 45˚ rotational charge-coupled device collects the scattered light intensity, which is converted into electrical signals and analyzed in a microprocessor. Data reduction consists of a mathematical convolution based on scattering model sets, each calculated from the general Mie theory for narrow distributions of isotropic spheres having a specific index of refraction and suspended in a liquid having a specific index of refraction. Data reported by the Saturn DigiSizer 5200® relates directly to an equivalent Mie sphere. The Mie theory consists of a "real" refractive index (1.550 for soils) and an "imaginary" refractive index (0.100 for soils) determined by Micromeretics Laboratories. The predictive model error (weighted residual) is proportional to the measure of the calculated Mie theory model to predictions of the observed laser-light scattering pattern.

Laser particle-size analysis was conducted using two categories of liquid media. All samples were analyzed using deionized water as one liquid medium (standard procedure). No pretreatment to remove carbonates, organic matter, or salts was preformed on the samples prior to particle-size analysis. A subset of bulk samples was passed through a 100 μm mesh sieve to provide a representative dust sample. This subset also was analyzed using each of three gun lubricants as the liquid medium. The index of refraction value used for all lubricants was provided to DRI by Micromeretics (see Appendix C). Note: all output files are available in electronic format from DRI.

Carbonate content: Total soil carbon (C) is a combination of both the inorganic fraction, primarily $CaCO_3$, and organic C. Total soil C is directly determined using a Perkin-Elmer CHN 2400 (Nelson and Sommers, 1996). Samples are oxidized at 1000° C, converted to CO_2 gas, and analyzed by thermal conductivity detectors. Inorganic C is determined by acid digestion in a Chittick apparatus to measure the volume of CO_2 gas evolved (Dreimanis, 1962; Machette, 1986). This volume is converted to elemental inorganic C and subtracted from total C to calculate total organic C.

Electrical conductivity and pH: Total soluble salts are estimated from electrical conductivity (EC) of aqueous soil extracts. Pure water is a poor conductor, as water containing dissolved salts conducts a current proportional to the amount of salt present. A soil-water extract of 1:5 is used in conjunction with a conductivity bridge to estimate the total amount of soluble salt.

Hydrogen-ion activity (pH) of the soil is measured from a 1:1 soil-aqueous matrix suspension. Calcium chloride ($CaCl_2$) is used because it offers several advantages over water, including the following: (1) the pH is almost independent of the degree of dilution over a wide range; (2) the pH is almost independent of the soluble-salt concentration for non-saline soils; and (3) this method provides a good approximation of the field pH for agricultural soils.

Soluble salts and elemental analysis: Personnel at DRI and NBMG Analytical Laboratory operate state-of-the-science Dionex Ion Chromatographs, which were used to analyze the anion concentration of soil extracts. The NBMG Analytical Laboratory also uses a Philips PW1404 XRF spectrometer for routine analyses of geologic materials. Since the XRF analyzer at NBMG went out of specification on 12 July 2004, vehicle samples were re-routed to ALS Chemex for XRF analysis using techniques identical to those used by the NBMG Analytical Laboratory. Major oxides were determined on borate-fused disks of crushed sample powder.

Mineralogy: Routine mineral identifications were performed on the <2000 μm size fraction using a Philips automated XRD at NBMG. Data were acquired on a PC using

MDI Datascan software and processed using the MDI Jade and ICDD PDF minerals database. Small (<1 g) splits of both bulk and tactical vehicle samples were smeared across glass plates using petroleum jelly as a binding agent. Note: all output files are available in electronic format from DRI.

ANALYTICAL RESULTS

Mineralogy and Geochemistry

Mineralogy: XRD analysis indicated that the samples contain a broad range of minerals (Table 4). Sample TV12-SI was not analyzed due to insufficient sample mass. All of the samples (except B10-SI) contain significant amounts of quartz (SiO_2). Sample B10-SI contains only a minor amount of quartz. Other silicate minerals identified in most of the bulk dust samples (as major or minor presence) include potassium feldspar ($KAlSi_3O_8$) and plagioclase ($NaAlSi_3O_8$). Two carbonate minerals were identified in the samples. First, calcite ($CaCO_3$) occurs in all samples analyzed and has either a major or minor presence in all but two of the samples. Second, dolomite [$CaMg\ (CO_3)_2$] was identified in three of the samples. Three evaporate minerals—halite (NaCl), gypsum ($CaSO_4.2H_2O$), and bassanite ($CaSO_4 \bullet 0.5H_20$)—occur in several of the samples. Halite is a primary mineral in two of the samples (B9-SI, and B15-SI). Seven different clay minerals were identified in 10 of the 14 samples analyzed. Identified clay minerals include kaolinite [$Si_4Al_4O_{10}(OH)_8$], montmorillonite [$(Al, Fe^{2+}, Mg)_4Si_8O_{20}(OH)_4$], saponite [$(Li,Mg)_4Si_8O_{20}(OH)_4$], and polygorskite [$(Mg,Al)_5(Si,Al)_8O_{20}(OH)_2{\cdot}8H_2O)$]. Clay mineral abundance ranges from minor to trace for most of the 15 samples. It is likely that additional clay minerals are present or present in higher concentrations than indicated by bulk sample XRD analysis. Additional XRD analysis of the clay and fine-silt fraction (<20 μm) isolated from each sample will enhance identification of clay minerals.

Mineralogy is similar between the bulk samples and the samples collected from tactical vehicles. Clay minerals, however, occur in relatively greater frequency and abundance in the samples collected from tactical vehicles relative to the bulk samples (Table 4).

Table 4. Mineralogy of Iraqi bulk (B) and tactical vehicle (TV) samples based on XRD analysis.

Sample ID	Silicates				CO_3^{-2*}		Evaporites			Clay Minerals				
	Quartz	Plagioclase	K-feldspar	Muscovite	Calcite	Dolomite	Halite	Gypsum	Bassinite	Illite	Chlorite	Saponite	Kaolinite	Montmorillonite
B1-GZ	●●●	●●			●●●	●●				●●		●●	●●	
B6-SI	●●●	●●●	●●●	●●●	●●	●●		●						
B7-SI	●●●	●	●		●									
B8-SI	●●●	●●	●		●●									
B9-SI	●●●	●●			●●		●●●	●●						
B10-SI	●●	●●			●●●								●	●●
B11-SI	●●●		●●		●									
B14-SI	●●●	●●	●●	●	●●				●●					
B15-SI	●●●			●	●●●	●●	●●●						●	
TV2-GZ	●●●	●●		●●	●●●				●●		●			
TV3-GZ	●●●	●●●		●●	●●●						●●		●●	
TV4-GZ	●●●	●●	●●	●●	●●●								●●	
TV5-GZ	●●●	●●	●●	●	●●●								●	●
TV12- SI	ND **													
TV13-SI	●●●	●●	●●	●	●●				●●					

*Carbonates
** No data: sample of insufficient size for XRD

Relative amounts of mineral abundance:

- ●●● major (primary mineral)
- ●● minor (secondary mineral)
- ● trace (low abundance)

Major cations: XRF analysis of major cations indicated that both the bulk samples and tactical vehicle samples are composed of a wide range of inorganic material (Table 5, Figure 2). Analysis also indicated that the concentration range of major cations is similar between the bulk and tactical vehicle samples.

The three primary components of the samples are silica (SiO_2), calcium, and magnesium ($CaO + MgO$) as well as the loss on ignition (LOI) fraction. The LOI component is the loss of organics, moisture, carbonates, and sulfides during analysis due to valorization. The combined totals of these four components range from 79.2% (TV5-GZ) to 94.3% (B11-SI). In sample B11-SI (southern Iraq eolian dune sand), the silica content is 89.8%, calcium and magnesium content is 2.9%, and LOI content is 1.6%. In the second sample identified as B15-SI (Basrah International Airport; desiccated marsh), silica content is 35.4%, calcium and magnesium content is 26.4%, and LOI content is 22.8%. The range in major cations largely reflects the difference in mineralogy between sample B11-IS, which contains abundant quartz-rich sand and sample B15-SI, which contains abundant halite- and calcite-rich floodplain sediments.

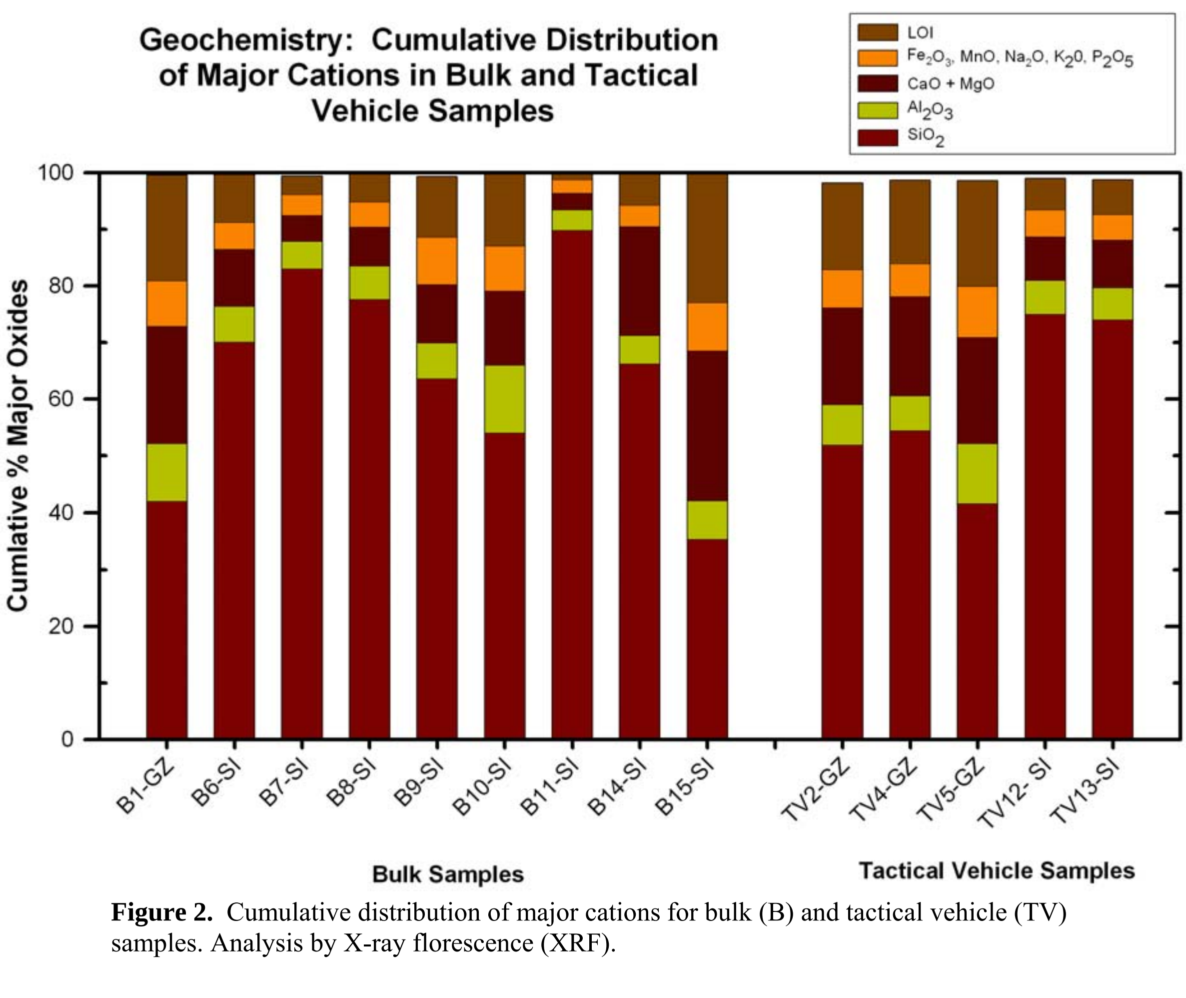

Figure 2. Cumulative distribution of major cations for bulk (B) and tactical vehicle (TV) samples. Analysis by X-ray florescence (XRF).

Table 5. Major cations (determined by XRF) for bulk (B) and tactical vehicle (TV) samples from Iraq

	Major Cations (as Oxides)												Primary (%)
Sample ID	**SiO_2(%)**	**TiO_2(%)**	**Al_2O_3(%)**	**Fe_2O_3(%)**	**MnO(%)**	**MgO(%)**	**CaO(%)**	**Na_2O(%)**	**K_2O(%)**	**P_2O_5(%)**	**LOI(%)**	**Total(%)**	**ΣSiO_2, CaO, MgO, LOI**
Bulk Samples													
B1-GZ	42.1	0.55	10	5.11	0.11	5.16	15.6	0.45	1.58	0.19	18.7	99.6	81.6
B6-SI	70.1	0.34	6.33	2.2	0.05	2.22	7.8	0.6	1.52	0.06	8.39	99.6	88.5
B7-SI	83	0.21	4.85	1.29	0.02	0.95	3.62	0.51	1.62	0.03	3.32	99.5	90.9
B8-SI	77.6	0.32	5.93	1.64	0.03	1.28	5.58	0.76	1.59	0.05	5.01	99.8	89.5
B9-SI	63.6	0.25	6.32	1.59	0.03	1.77	8.55	5.24	1.22	0.05	10.7	99.3	84.6
B10-SI	54	0.53	12	5.37	0.07	5.67	7.42	0.1	1.76	0.1	13.2	100.2	80.3
B11-SI	89.8	0.1	3.64	0.61	0.01	0.49	2.45	0.36	1.23	0.03	1.57	100.3	94.3
B14-SI	66.2	0.42	5.01	1.42	0.05	1.75	17.47	0.54	1.34	0.06	5.78	100	91.2
B15-SI	35.4	0.41	6.78	3.33	0.06	7.69	18.68	3.74	0.82	0.14	22.8	99.8	84.6
Tactical Vehicle Samples													
TV2-GZ	51.89	0.44	7.11	3.77	0.08	2.91	14.27	1.16	1.03	0.12	15.3	98.3	84.4
TV3-GZ	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*
TV4-GZ	54.44	0.37	6.12	3.28	0.07	2.76	14.8	1.09	0.87	0.08	14.7	98.8	86.7
TV5-GZ	41.7	0.61	10.46	5.4	0.11	5.12	13.65	1.54	1.07	0.15	18.7	98.7	79.2
TV12- SI	75.01	0.28	6	1.67	0.03	1.26	6.41	1.27	1.33	0.05	5.55	99.1	88.2
TV13-SI	74.02	0.3	5.64	1.65	0.03	1.53	6.89	1.2	1.19	0.04	6.14	98.9	88.6

ND : Insufficient sample mass for analysis.

The remaining cations measured in the bulk dust samples include titanium (TiO_2), aluminum (Al_2O_3), iron (Fe_2O_3), sodium (Na_2O), potassium (K_2O), and phosphorus (P_2O_5). The largest combined total concentration of these cations is in sample B10-SI (playa) at 19.9%, and the lowest concentration is in sample B11-SI (eolian dune sand) at 6.0%. The varying concentrations of these cations reflect the relative contents of potassium feldspar, plagioclase, and clay minerals in the samples. Cation content increases with a greater abundance of silicate and clay minerals.

Major anions: Water-soluble anions also occur in a wide range of concentrations (Table 6, Figure 3). Sulfate (SO_4^{2-}) and chloride (Cl^-) concentrations determined by ion chromatography (IC) in both bulk samples and tactical vehicle samples occur in the greatest amounts relative to measured concentrations of nitrate (NO_3^-). The combined total concentrations of the three anions range from 672 ppm (B1-GZ) to 64,718 ppm (B15-SI). Sulfate is present in nearly all of the samples and exceeds 10,000 ppm (~1% sample weight) in nine of the samples. Sample B14-SI has a significant concentration of sulfate due to the presence of the mineral bassanite [$CaSO_4 \cdot 0.5H_20$], a type of gypsum mineral. Two samples, B9-SI and B15-SI, contain high concentrations of chloride, which indicates the presence of halite.

Table 6. Water-soluble anion concentrations (determined by IC) for bulk and tactical vehicle samples from Iraq

DRI ID	Sample ID	Cl^- (ppm)	NO_3^- (ppm)	SO_4^{2-} (ppm)
Bulk Samples				
04-1555	B1-GZ	61.8	3.42	604
04-1562	B6-SI	107	5.38	7190
04-1563	B7-SI	84.4	18.4	8250
04-1564	B8-SI	142	11.6	9730
04-1565	B9-SI	37600	66.3	18200
04-1566	B10-SI	356	61	1480
04-1567	B11-SI	591	55.5	11200
04-1568	B14-SI	69.1	23.7	40800
04-1569	B15-SI	51000	16.3	13700
Tactical Vehicle Samples				
04-1556	TV2-GZ	1440	43.9	20300
04-1557	TV3-GZ	*ND*	*ND*	*ND*
04-1558	TV4-GZ	1690	91.9	10500
04-1559	TV5-GZ	9240	15.95	14000
04-1560	TV12- SI	1090	92.83	19100
04-1561	TV13-SI	569	55.4	20300

ND : No data, insufficeint sample mass for analysis.

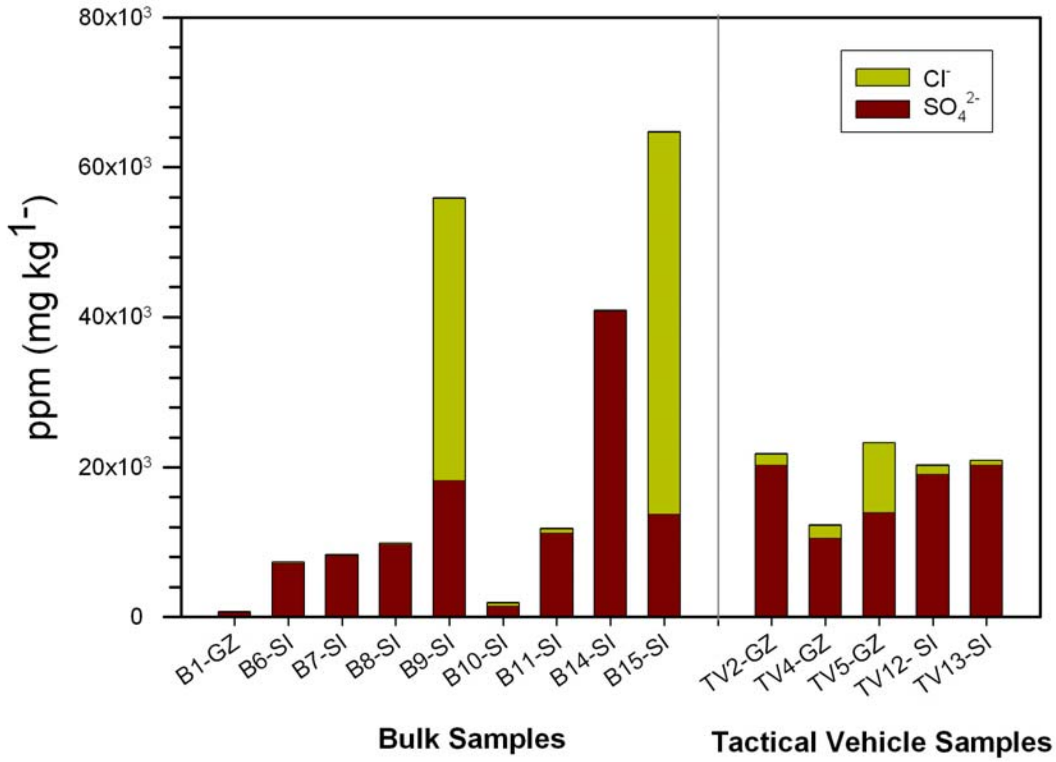

Figure 3. Cumulative distribution of major anions (determined by IC) for bulk and tactical vehicle samples

Carbonate and soluble salts: Calcium carbonate content (Table 7, Figure 4) in all samples (n=14) ranges from 28.4% weight in B1-GZ to a low of 3.0% weight in sample B11-SI. Samples with identified calcite or dolomite minerals (Table 4) have the greatest carbonate content. Carbonate content is higher overall in the samples collected from the tactical vehicles (average 18.2% wt.) than in the bulk samples (average 12.3% weight).

Total soluble salt content (determined by electrical conductivity measurements) in all samples (n=13) had a range of 17.2% weight in sample B15-SI to 0.3% weight in sample B1-GZ (Table 7, Fig. 4). The two samples with the highest salt content (B9-SI and B15-SI) also contain halite (Table 4). Electrical conductivity of 1:5 (soil to solution) extracts is presented in Table 4.

pH: Measured pH (Table 7) of the nine bulk samples is largely neutral to basic and ranges from a high of 8.9 (B9-SI) to a low of 6.9 (B1-GZ). Vehicle dust samples had neutral values and less variability with pH ranging from 7.5 to 7.7.

Carbon content: Total elemental C content (determined by CHN analysis) in all samples ranges from a high of 4.6% in sample TV3-GZ to a low of 0.29% in sample B11-SI (Table 7). Most of the C in the nine bulk samples is associated with inorganic C (e.g., carbonate) with a relatively smaller fraction associated with organic C.

Nitrogen: Total elemental N content is very low for all bulk samples and averages just 0.03% (Table 7).

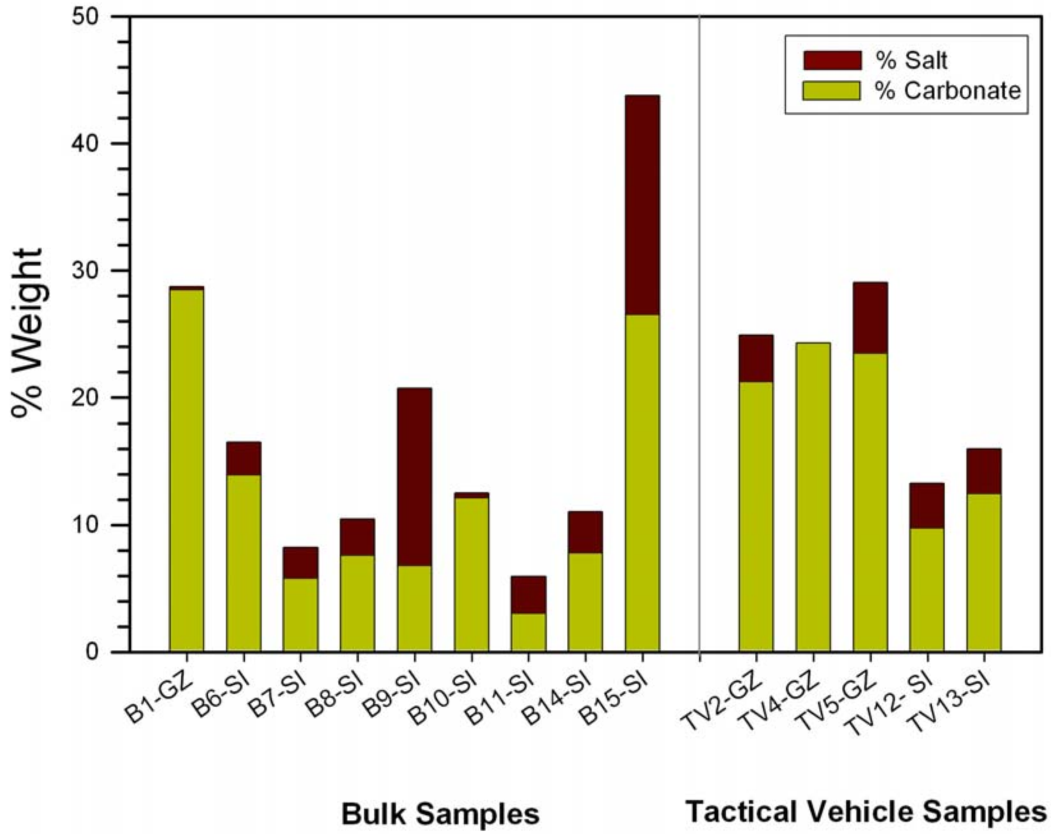

Figure 4. Cumulative distribution of total soluble salts (based on EC) and carbonates for bulk and tactical vehicle samples. All measured samples contain carbonate and most contain soluble salt.

Table 7. Summary of total soluble salt (EC), pH, total elemental C, and N (CHN analysis) and total carbonate data for bulk (B) and tactical vehicle (TV) samples from Iraq.

		Elect. Cond.				Carbon			
DRI ID	Sample ID	1:5 Paste dS/m	Souble Salts - % -	pH	Nitrogen - % -	Total - % -	Organic - % -	Inorganic - % -	$CaCO_3$ - % -
Bulk Samples									
04-1555	B1-GZ	0.36	0.3	6.9	0.12	4.47	1.1	3.4	28.4
04-1562	B6-SI	2.95	2.6	7.5	0.00	0.62	-1.1	1.7	13.9
04-1563	B7-SI	3.44	2.4	7.7	0.01	0.91	0.2	0.7	5.8
04-1564	B8-SI	3.70	2.9	7.8	0.01	1.16	0.2	0.9	7.6
04-1565	B9-SI	16.8	13.9	8.9	0.01	2.93	2.1	0.8	6.8
04-1566	B10-SI	0.96	0.4	7.9	0.05	1.93	0.5	1.5	12.1
04-1567	B11-SI	3.41	2.9	7.9	0.01	0.29	-0.1	0.4	3.0
04-1568	B14-SI	2.76	3.3	7.7	0.02	1.32	0.4	0.9	7.8
04-1569	B15-SI	22.3	17.2	8.1	0.05	3.96	0.8	3.2	26.5
Tactical Vehicle Samples									
04-1556	TV2-GZ	5.70	3.7	7.5	0.09	4.49	1.9	2.5	21.2
04-1557	TV3-GZ	*ND*	*ND*	*ND*	0.06	4.56	*ND*	*ND*	*ND*
04-1558	TV4-GZ	*ND*	*ND*	*ND*	0.06	3.52	0.6	2.9	24.3
04-1559	TV5-GZ	8.70	5.6	7.6	0.01	1.26	-1.6	2.8	23.5
04-1560	TV12- SI	5.73	3.6	7.6	0.01	1.24	0.1	1.2	9.7
04-1561	TV13-SI	5.50	3.5	7.7	0.03	1.99	0.5	1.5	12.4

ND: No data, insufficeint sample mass for analysis.

Particle-Size Distribution

Particle-size distribution of the nine bulk dust samples varies considerably and largely reflects environmental controls on sediment deposition (Table 8; Figures 5, 6; Appendix B). Sample results described below are grouped by depositional environment.

Eolian (sand dune): The sample with the coarsest texture is B11-SI and is comprised of 95% sand with silt and clay content less than 5%. Sample B11-SI also has the highest mean (373 µm) and median (378 µm) particle diameters, further demonstrating the sand-rich texture of this sample. The high sand content and corresponding low silt and clay content are expected for active dune deposits where frequent re-working of the sand by wind results in a high concentration of sand-sized particles.

Fluvial (marsh, playa, slackwater): Three samples that are closely grouped—B1-GZ, B15-SI, and B10-SI—represent the finest textures of the nine bulk samples. These three samples have clay content ranging from 32 to 36%, silt content ranging from 50 to 56%, and sand content ranging from 10 to 15%. The three samples have mean particle diameters ranging from 15 to 19 µm, with median particle diameters ranging from 4 to 7 µm. High clay and silt content is consistent with this type of sediment, which is deposited under slow-moving or ponded water (environmental processes that favor deposition of small particles).

Fluvial (intertidal area): The particle-size distribution of samples B6-SI and B9-SI reflects more active, dynamic, fluvial environments of intertidal zones where mixtures high in sand and silt and low in clay are commonly deposited. These two samples have moderate clay content of 10 to 14%, silt content of 20 to 23%, and an enriched sand content of 66 to 67%. These samples have mean particle diameters ranging from 101 to 148 µm, with median particle diameters ranging from 114 to 86 µm.

Regional soils: Particle-size distribution of the three regional soils—samples B7-SI, B8-SI, and B14-SI—is largely representative of soils formed on desert surfaces that have a lag layer of gravel (15–21% gravel content) or desert pavements. Sand content ranges from 67 to 89%. These samples have mean particle diameters ranging from 176 to 206 µm, with median particle diameters ranging from 114 to 143 µm.

Table 8. Summary of particle-size distribution data for bulk and tactical vehicle samples from Iraq

DRI Lab ID	Sample ID	Gravel >2 mm	SAND >62.5 µm	SILT 15 µm	SILT 3 µm	CLAY <3 µm	<1000 µm Fraction Mean	<1000 µm Fraction Median	<1000 µm Fraction Mode	Cum. Particle Diam (µm) %finer 90%	Cum. Particle Diam (µm) %finer 10%
Bulk Samples											
04-1555	B1-GZ	0.0	10	20	36	35	19	7	8	49	1.0
04-1562	B6-SI	9.9	66	7	13	14	101	40	294	296	1.5
04-1563	B7-SI	19.1	89	4	5	3	206	137	366	510	5.3
04-1564	B8-SI	15.2	84	5	5	5	176	143	346	412	2.9
04-1565	B9-SI	14.6	67	12	11	10	148	86	325	396	2.0
04-1566	B10-SI	0.0	12	13	43	32	15	5	5	28	0.7
04-1567	B11-SI	0.2	95	1	2	2	373	378	436	602	115
04-1568	B14-SI	21.3	73	9	10	8	202	114	449	560	3.6
04-1569	B15-SI	1.5	15	17	33	35	17	4	3	56	0.4
Tactical Vehicle Samples											
04-1556	TV2-GZ	8.1	34	19	23	23	74	23	258	278	1.1
04-1557	TV3-GZ	0.0	35	34	21	10	73	37	95	214	3.0
04-1558	TV4-GZ	13.0	34	19	23	23	68	18	160	218	1.1
04-1559	TV5-GZ	8.1	9	23	34	34	21	6	4	58	0.8
04-1560	TV12- SI	1.6	57	13	16	14	132	89	165	342	1.9
04-1561	TV13-SI	4.5	60	13	15	12	149	99	366	393	2.2

µm = microns or 0.001 mm particle diameter

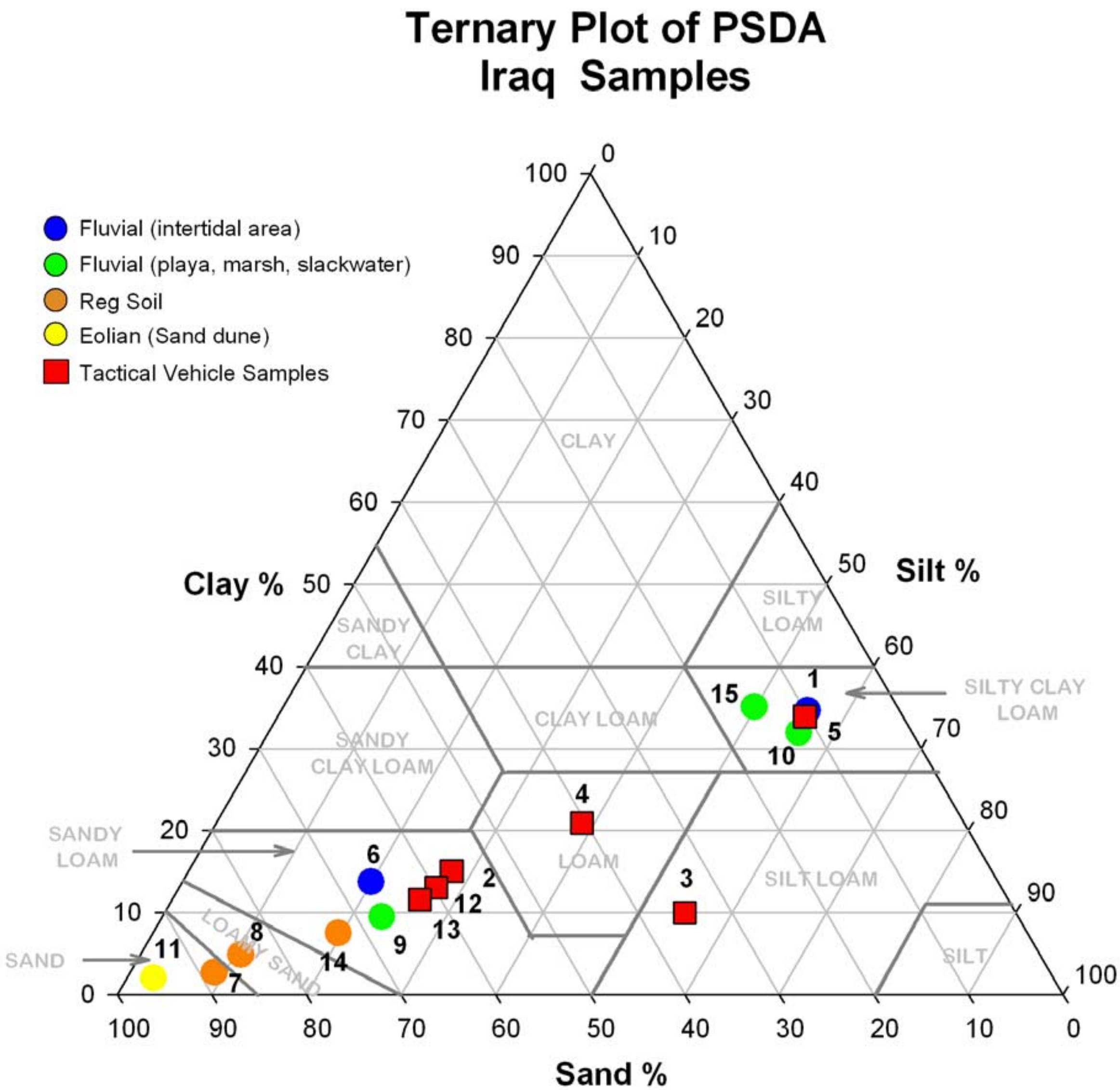

Figure 5. Distribution of the relative proportions of sand, silt, and clay for all 15 samples. Texture of the nine bulk samples largely reflects environmental settings. Numbers are sample ID numbers (see Table 1).

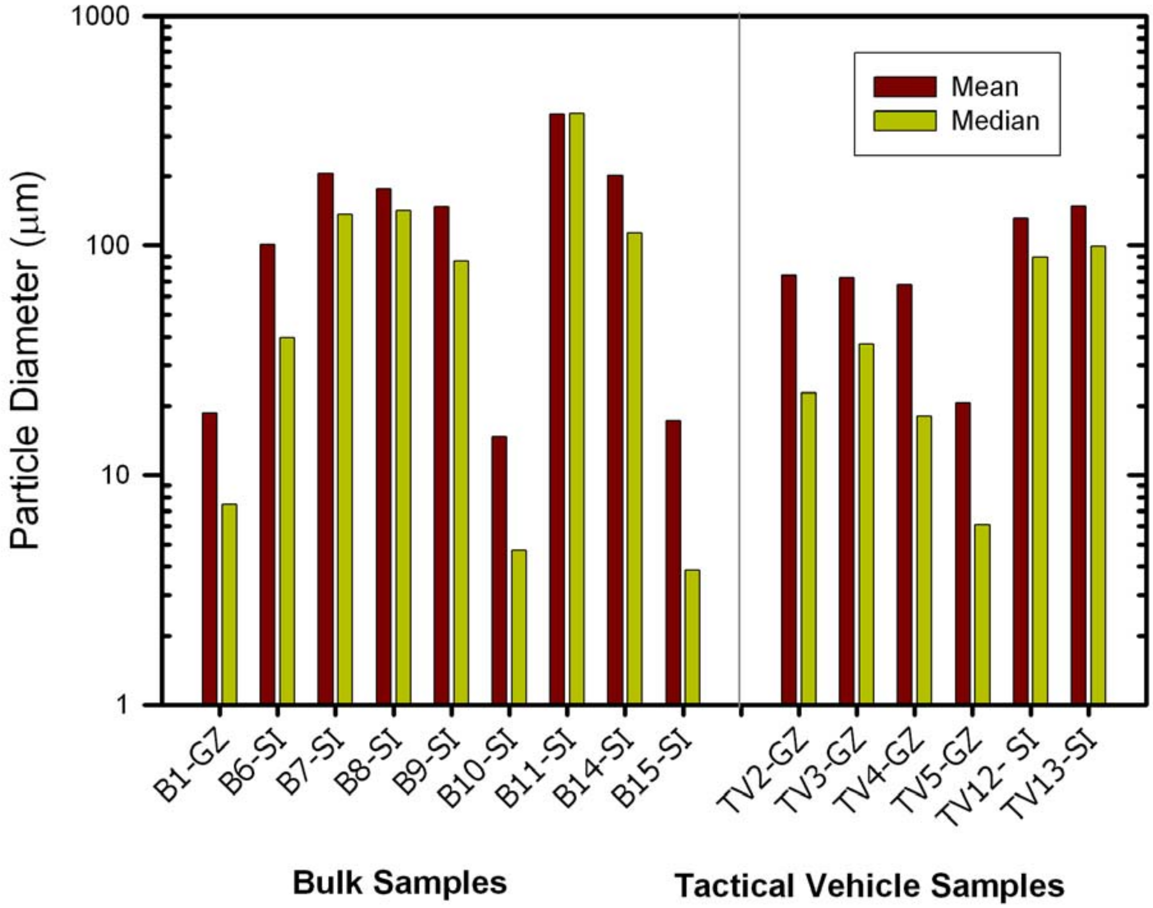

Figure 6. Mean and median particle diameters for Iraqi bulk (B) and tactical vehicle (TV) samples.

Tactical vehicle samples: The six samples collected from the tactical vehicles are characterized by more silt and slightly more clay relative to most of the bulk dust samples (Tables 8, 9; Figures 5, 6; Appendix C). Only the three bulk samples from depositional settings that favor deposition of silt and clay have textures finer than five of the tactical vehicle samples. Sample TV5-GZ has a texture similar to the three bulk samples high in silt and clay. Samples from tactical vehicles operated around southern Iraq have higher overall sand content and mean particle diameters relative to samples from tactical vehicles operating around the green zone.

Variation in particle-size distribution for all tactical vehicle dust samples is less than the variation in the bulk dust samples (Figure 6). The source of the dust collected from tactical vehicle samples is largely aerosolic sediment trapped on vehicle surfaces or within internal compartments, a process that enhances deposition of silt- and clay-size particles. Five of the tactical vehicle samples also include material collected from wheel wells and floorboards. Sediment accumulated in these areas probably includes larger particles delivered by well splash (wheel well) and dispersal from soldier uniforms and boots (floor boards).

Particle-Size Distribution in Weapon Lubricants

Iraqi samples: A water-surfactant medium and ultra-sonication were used to fully disperse the previously described particle-size distributions. In addition, three lubricants were used in place of the water-surfactant medium in an effort to explore particle interaction within a lubricant medium (Tables 9–11, Figures 7–11; Appendix C). Analog dust samples were produced by dry sieving bulk dust samples to <100 µm, thereby concentrating silts and clays. Three bulk dust samples—B9-SI, B10-SI, and B15-SI—were chosen based on their large sample size, elevated clay content, high salts, and mineralogy. These samples were analyzed for particle-size distribution in triplicate within the water-surfactant medium to ensure the reproducibility of the laboratory equipment (Table 9). Separate chemical analysis of the sieved fraction (<100 µm) is presented in Table 10.

Distribution frequencies in all three lubricants show a sharp increase in ~100 µm particles and a corresponding decrease in <20 µm particles compared to the same samples dispersed in water (Figure 7). The most striking illustration of a shift in size distribution occurred with sample B10-SI. Changes in particle-size distribution were strongly similar for all three gun lubricants. Mean and medium particle sizes also increased for all three samples (Figure 8; Table 11). The change in size distribution indicates the occurrence of flocculation and the formation of sand-size aggregates.

Particle-size distribution of five tactical vehicle samples exposed to gun lubricants also displayed a clear shift in particle-size distribution compared to the same samples dispersed in water (a significant increase in ~100 µm particles and a corresponding decrease in <20 µm particles; Figure 9). Increases in mean particle diameter also occurred when tactical vehicle dust samples were suspended in all three oils (Figure 9; Table 11). These results indicate that formation of sand-size aggregates also is occurring in tactical vehicles samples exposed to gun lubricants. The range of increase in particle-size distribution varied from slight (sample TV13-SI) to severe (TV5-GZ). The range of the shift in particle-size distribution reflects, in part, the amount of particles <20 µm, with the largest shift corresponding with samples high in fine silt and clay. As with the bulk samples, changes in particle-size distribution were similar for all three gun lubricants.

Internal laboratory standards: Three laboratory standards (milled garnet and two soil samples) were used to evaluate possible reactions between gun lubricants and mineral particles as well as to verify analytic validity (Figure 10). Garnet is largely inert, and the sample used was milled to a very narrow particle-size distribution. Minimal change in particle-size distribution and mean particle size indicated a near complete lack of flocculation of garnet in all but the Strikehold lubricant, which had a small increase in ~100 µm particles (Figure 10; Table 11). The milled garnet sample was expected to show only a limited reaction with the lubricants due to the lack of positive or negative surface charge on the garnet particles. The degree of surface charge and the ability to exchange ions has a strong control on flocculation and dispersion of mineral particles (McBride, 1989; 1994).

Two soil samples (Warden silt loam and Yolo soil) displayed variable response with exposure to the lubricants. Particle-size distribution of the Warden silt loam did not change, whereas the Yolo soil displayed a noticeable but moderate increase in coarse-silt and sand-size fractions. Both soil samples have minimal concentrations of soluble salts

(Table 10). The Yolo soil has a much greater abundance of fine silt and clay relative to the Warden soil, suggesting that an abundance of small soil mineral particles (<20 μm) will react with gun lubricants leading to the formation of larger particle aggregates through flocculation. In other words, the shift in particle-size distribution appears to be based in part on the amount of <20 μm particles that are likely to have reactive surfaces.

YPG soil samples: Results above suggest that an abundance of fine silt and clay particles may be one reason for the measured increase in flocculation and formation of particle aggregates. The presence of soluble salts also may enhance formation of aggregates. This hypothesis is based in part on the generally large shift in particle-size distribution for the Iraqi samples (which contain abundant concentrations of soluble salts), but a relatively smaller shift in the Yolo sample (minimal soluble salts).

Two soil samples from YPG were selected to test this hypothesis. Sample YPG-Av is a sample from the soil surface that is high in fine silt and clay but has a low concentration of soluble salts (0.1%; Table 10). By comparison, sample YPG-Btk has a higher concentration of soluble salt (1.5%; Table 10). We found a minimal shift in particle-size distribution of sample YPG-Av in all three gun lubricants but a pronounced shift in particle-size distribution in sample YPG Btk in all three gun lubricants (Figure 11). Likewise, there is a corresponding similar change in mean particle size, with a significantly large increase in sample YPG-Btk (Figure 8; Table 11). These results suggest that a combination of soluble salts and an abundance of <20 μm particles is required for significant flocculation and formation of sand-sized aggregates.

Table 9. Mean (± standard deviation) of particle-size distribution data for analog dust samples (dry sieved to <100 μm) and laboratory standards dispersed in water-surfactant media.

				Cum. Particle Diam (μm) %finer		
Sample ID	**Mean**	**Median**	**Mode**	**90%**	**10%**	***Reps***
B9-SI (<100 μm)	37.6 ± 0.3	24.2 ± 0.4	77.6 ± 1.9	97.7 ± 1.0	1.53 ± 0.1	3
B10-SI (<100 μm)	11.5 ± 0.3	5.0 ± 0.1	4.5 ± 0.0	27.1 ± 0.5	0.95 ± 0.0	3
B15-SI (<100 μm)	19.0 ± 0.2	5.6 ± 0.0	3.9 ± 0.0	63.0 ± 1.0	0.74 ± 0.0	3
Yolo Silt Loam	29.3 ± 2.4	10.8 ± 1.3	44.6 ± 4.8	86.1 ± 7.2	1.21 0.102	62
Warden Silt Loam	54.1 ± 2.5	39.0 ± 2.6	72.056 ± 1.557	127.7 ± 4.7	3.03 0.2	37
	250 μm	**125 μm**	**62.5 μm**	**15 μm**	**3 μm**	**<3 μm**
B9-SI (<100 μm)	0.0 ± 0.1	3.4 ± 0.3	21.4 ± 0.5	33.0 ± 0.1	24.3 ± 0.5	17.9 ± 0.4
B10-SI (<100 μm)	0.0 ± 0.0	0.6 ± 0.2	3.2 ± 0.0	14.1 ± 0.1	48.1 ± 1.2	34.1 ± 1.0
B15-SI (<100 mm)	0.0 ± 0.0	0.5 ± 0.1	9.6 ± 0.2	21.5 ± 0.2	32.6 ± 0.4	35.8 ± 0.3
Yolo Silt Loam	0.3 ± 0.4	4.3 ± 0.8	10.0 ± 0.6	28.7 ± 1.5	31.8 ± 1.0	24.8 ± 1.9
Warden Silt Loam	0.5 ± 0.3	10.0 ± 0.7	24.8 ± 0.9	34.2 ± 0.5	20.5 ± 0.9	10.0 ± 0.6

μm = microns or 0.001 mm particle diameter

Table 10. Anion concentrations and soluble salts of laboratory standards and analog dust samples

DRI ID	Sample ID	Soluble Anions Cl^-	NO_3^-	SO_4^{2-}	Elect. Cond. 1:5 Paste	Soluble Salts
		- ppm -	- ppm -	- ppm -	- dS/m -	- % -
STD	Yolo	7.1	2.5	31.6	0.12	0.0
STD	Warden	10.9	11.9	51.8	0.13	0.0
01-310	YPG Av Horizon	59.3	6.8	36.9	0.21	0.1
01-313	YPG Btk Horizon	3080	376	9180	4.65	1.5
04-1565	B9-SI (<100 μm)	32186	18.6	14300	18.5	5.9
04-1566	B10-SI (<100 μm)	3495	12.3	3840	1.5	0.5
04-1569	B15-SI (<100 μm)	39592	22.1	14600	19.6	6.2

Table 11. Mean particle diameter for analog dust samples, tactical vehicle samples, and laboratory standards dispersed in water-surfactant and three gun lubricants.

Field ID	Mean Particle Diameter (μm) Water / Surfactant	CLP	Strike Hold	Militec-1
Analog Dust Samples				
B9-SI (<100 μm)	37.6	52.4	54.5	63.9
B10-SI (<100 μm)	11.5	45.4	50.1	61.1
B15-SI (<100 μm)	19.0	39.4	46.8	53.8
Tactical Vehicle Samples				
TV2-GZ	74.0	80.0	100.0	*ND*
TV3-GZ	*ND*	*ND*	*ND*	*ND*
TV4-GZ	67.6	98.1	*ND*	*ND*
TV5-GZ	20.6	64.8	126.7	116.5
TV12- SI	131.7	200.9	175.7	138.4
TV13-SI	148.8	159.5	165.8	175.4
Laboratory Standards and Soils				
Garnet	5.3	5.6	12.8	5.9
Warden Silitloam	54.2	59.3	55.7	59.1
Yolo Clay	29.4	50.8	58.9	63.7
YPG Av horizon	37.6	42.1	48.3	64.4
YPG Btk horizon	37.3	104.1	56.2	159.1

ND: No data, insufficeint sample mass for analysis.
μm = microns or 0.001 mm particle diameter

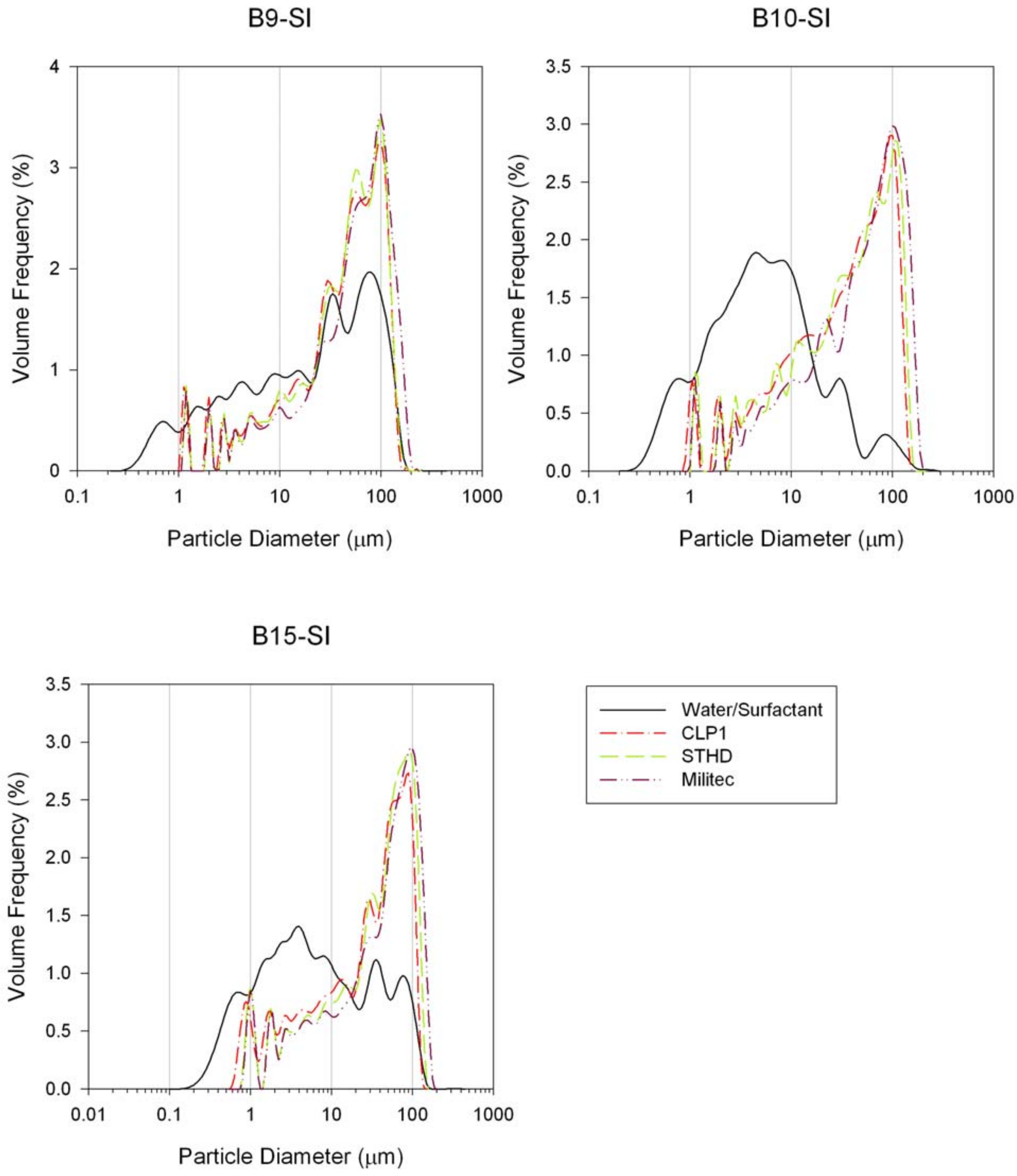

Figure 7. Distribution of particle diameters for three of the Iraqi analog dust samples (bulk samples dry sieved to <100 μm). Solid black line is the distribution of the samples dispersed in water. The dashed lines show distribution of the same sample dispersed in the respective weapon lubricant.

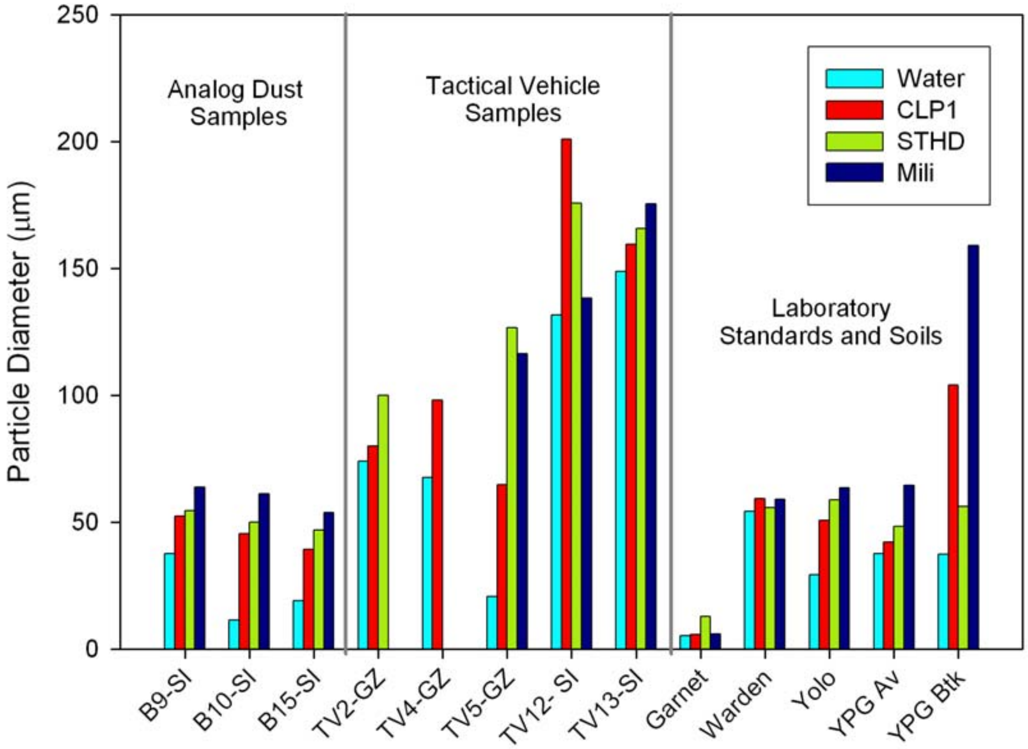

Figure 8. Mean particle diameters for Iraqi bulk samples, tactical vehicle samples, and laboratory standards.

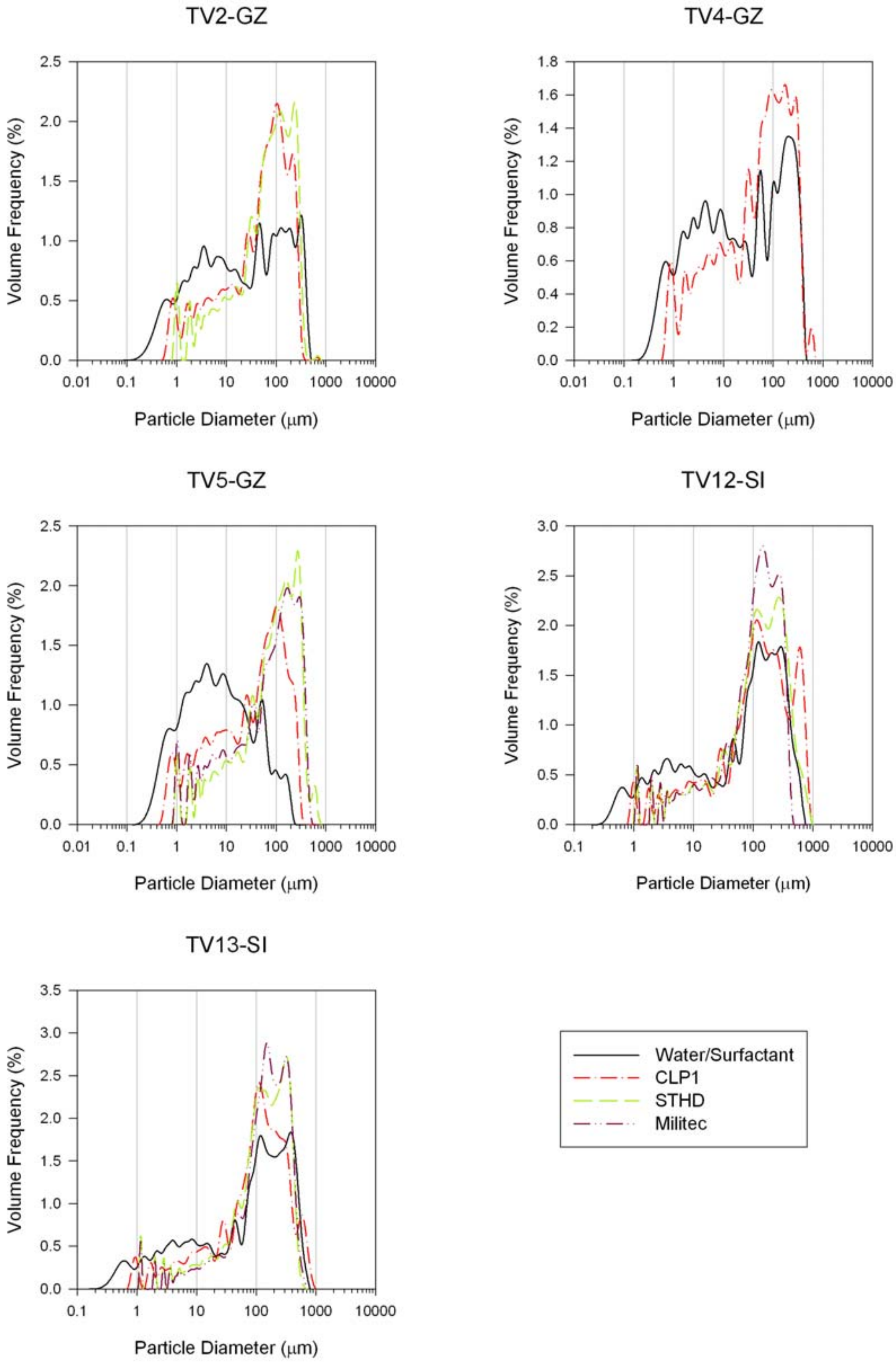

Figure 9. Distribution of particle diameters for five of the Iraqi tactical vehicle samples. Solid black line is the distribution of the sample dispersed in water. The dashed lines show distribution of the same sample dispersed in the respective weapon lubricant.

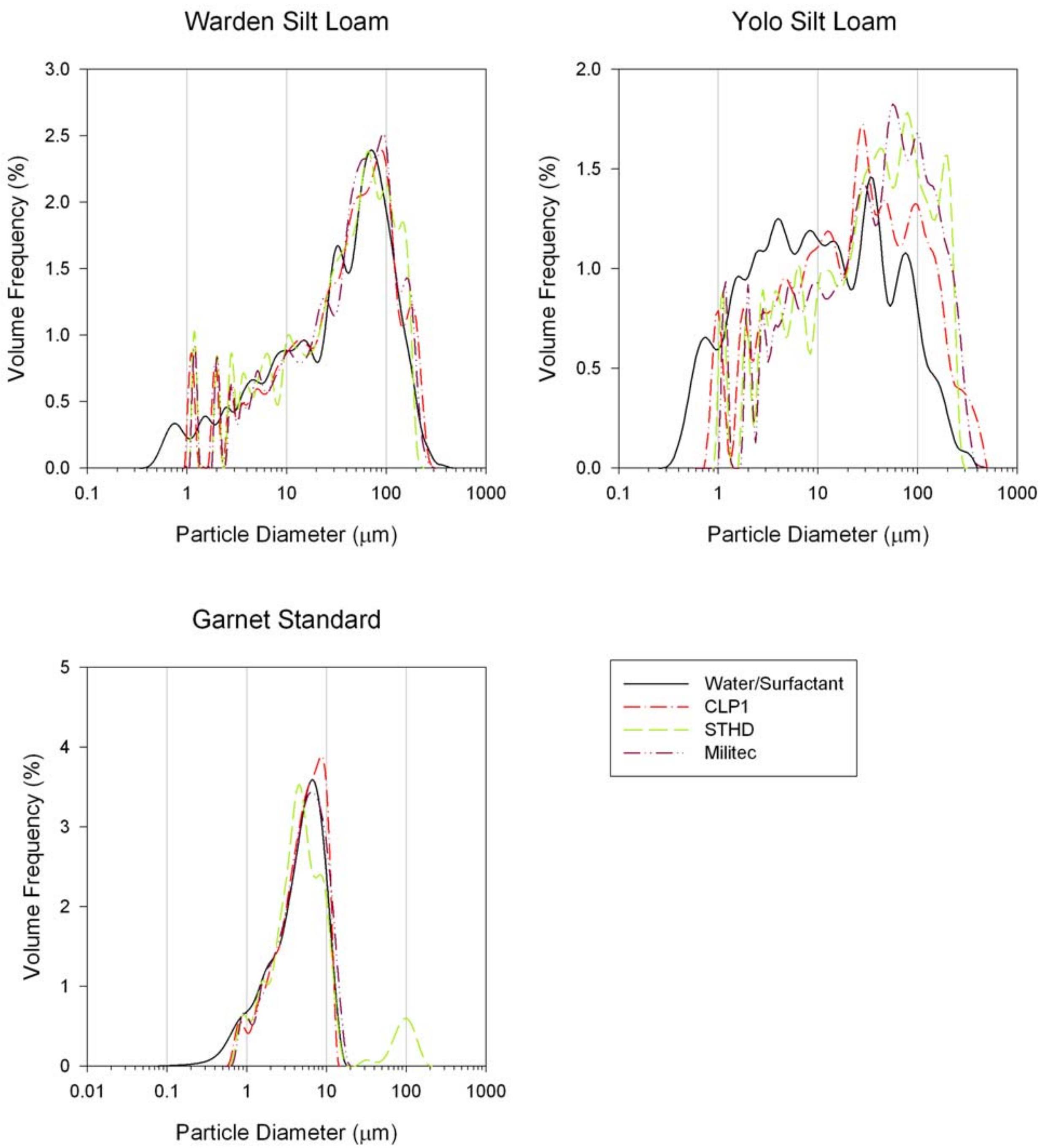

Figure 10. Distribution of particle diameters for three laboratory standards. Solid black line is the distribution of the sample dispersed in water. The dashed lines show distribution of the same sample dispersed in the respective weapon lubricant.

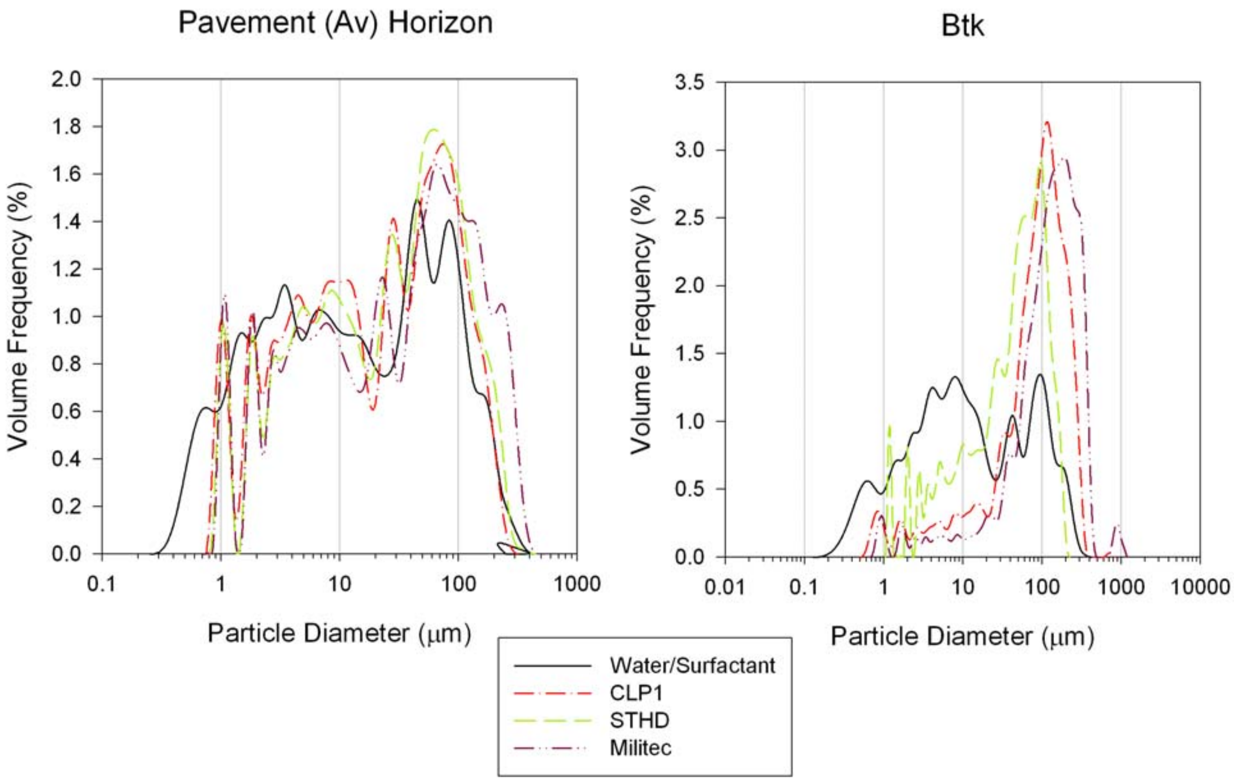

Figure 11. Distribution of particle diameters for a surface soil (Av Horizon) and a subsurface soil (Btk) from YPG. Solid black line is the distribution of the sample dispersed in water. The dashed lines show distribution of the same sample dispersed in the respective weapon lubricant.

FINDINGS AND CONCLUSIONS

Results presented above provide the first scientific analysis of soil, sediments, and dust in relation to military operations in Iraq. Fifteen samples were collected in the general vicinity of Baghdad and Basrah. Of these, nine were bulk samples collected from a wide range of environmental settings (eolian dunes, regional soils, intertidal areas, river plain). These samples provide a broad sampling of soil and sediments types that may serve as sources of dust. Another six samples were collected from the interiors and exteriors of tactical vehicles that are frequently used by Coalition Forces. These samples represent dust that is likely to be in everyday contact with military equipment. Although only 15 samples were analyzed, our results provide the basis for useful generalizations regarding the characteristics of Iraqi dust and potential impacts of this dust on military operations and equipment.

(1) *Key geochemical and physical attributes of the dust:* Results indicate that Iraqi dust contains a wide range of physical and chemical constituents. Overall characteristics of the 15 samples are summarized in Tables 12 and 13 and below:

- Although silica (quartz) is commonly the primary component, silica is usually less than 80% of the sample mass.
- Substantial amounts of soluble salt, carbonate, chlorides, and sulfates are present in nearly all of the samples.
- Halite (sodium chloride), gypsum (calcium sulfate), and bassanite (calcium sulfate) minerals were identified in six of the samples.
- A wide range of clay minerals occurs in the Iraqi samples. The three most common are muscovite, chlorite, and kaolinite.
- Most of the samples contain appreciable quantities of silt-sized (2–62 µm) and clay-sized (<2 µm) particles. The clay-sized fraction includes minerals as well as other clay-sized components. Average particle size of the sampled Iraqi dust is less than the average particle size of the dust used in current weapons testing procedures (Appendix D).

This finding is important because study results indicate that *the character of soils and dust collected from areas of military activity in Iraq is greatly different from the material used in current weapons testing procedures* and may be unlike natural geologic materials to which weapons are exposed during most training environments in the U.S.

(2) *Possible environmental sources of the dust:* The nine bulk soil and sediment samples collected represent a broad range of depositional environments common to areas where Coalition Forces conduct operations. Nearly all of the samples contain silt- and clay-sized particles suggesting that many of the soils and sediments exposed at the surface in regions served by Coalition Forces are likely to contribute to desert dust in this region.

(3) *Characteristics of dust that accumulates within tactical vehicles:* The six dust samples collected from tactical vehicles provide a good initial representation of the type of airborne sediment that is most likely to come into contact with military equipment and personnel. Bulk and tactical vehicle samples all have similar characteristics, although the *samples collected from tactical vehicles are commonly higher in sulfates as well as carbonate and contain a wider range of clay minerals.* Samples collected from tactical vehicles also have a *greater quantity of silt and clay* relative to most of the bulk dust samples. Initial results indicate that military equipment and personnel are likely to be extensively exposed to fine-textured dust during vehicular operation.

(4) *Potential for corrosion by dust constituents:* Chlorides, sulfates, and dissolved calcium (from carbonates) under the right conditions can produce severe corrosion to metals commonly used in military installations (Meyers et al., 2002). Overall, the Iraqi dust samples contain sufficient amounts of clay minerals, carbonates, sulfates, and chlorides to suggest that there is a strong potential for corrosion, pitting, and related impacts to military equipment. Carbonates also can enhance the formation of scale on metal alloys. A wide range of minerals identified in the Iraq samples exhibit surface charge where the surface of the mineral can have either a negative of positive charge. Surface charge on dust mineral particles can increase chemical processes promoting corrosion, especially through oxidation and reduction reactions.

(5) *Interaction occurs between all three military-grade weapon lubricants and Iraqi dust:* There appears to be a reaction between *all three common gun lubricants* (MILSPEC CLP Royal, Militec, and Strikehold) and Iraqi dust that promotes formation of aggregates, increasing the average particle size of the samples. There is a pronounced change in particle-size distribution indicating that clay and fine silt (diameter <20 μm) are combining (flocculating) with clay, silt, and/or sand to form coarse silt or sand-sized aggregates (diameter ~50–150 μm). One possible cause is neutralization or a strong decrease of repelling negative surface charges among clay-sized and fine-silt-sized particles. Another possibility is that the oil is preventing dissociation of electrolytes away from charged particles and into the surrounding oil, resulting in very high molar concentrations of ions around clay- and silt-sized particles. A very high concentration of electrolytes will produce extensive flocculated structures (McBride; 1994). Identification of the physiochemical process responsible for this aggregation will require further analysis.

(6) *Reaction with gun lubricants varies with mean particle size:* The extent of the reaction between the three gun lubricants and the dust and soil samples varied with different chemical compositions and grain sizes. In general, dusts higher in salt and carbonate concentrations and with smaller particles (<20 μm) are most reactive when mixed with gun lubricants.

Table 12. Summary table of analytical results for bulk (B) and tactical vehicle (TV) samples from Iraq

	XRD Results: Mineralogy														Extracts				Particle-Size Distribution					
	Silicates				CO_3^{-2}*		Evaporites			Clay Minerals														
Sample ID	Quartz	Plagioclase	K-feldspar	Muscovite	Calcite	Dolomite	Halite	Gypsum	Bassinite	Illite	Chlorite	Saponite	Kaolinite	Montmorillonite	Chloride	Sulfate	Soluble Salt	Carbonate	Sand	Silt	Clay	Mean Size (μm)	Medium Size (μm)	Texture
B1-GZ	●●●	●●			●●●	●●				●●		●●	●●		●	●	●	●●●	●	●●●	●●	19	7	silty clay loam
B6-SI	●●●	●●●	●●●	●●●	●●	●●		●							●	●●	●●	●●	●●●	●	●	101	40	sandy loam
B7-SI	●●●	●	●		●										●	●●	●●	●●●	●●●	●	●	206	137	sand
B8-SI	●●●	●●	●		●●										●	●●	●●	●●●	●●●	●	●	176	143	loamy sand
B9-SI	●●●	●●			●●		●●●	●●							●●●	●●	●●	●●	●●●	●	●	148	86	sandy loam
B10-SI	●●	●●			●●●								●	●●	●	●	●●	●●	●	●●●	●●	15	5	silty clay loam
B11-SI	●●●		●●		●										●	●●	●●●	●●	●●●	●	●	373	378	sand
B14-SI	●●●	●●	●●	●	●●				●●						●	●●●	●●	●●	●●●	●	●	202	114	sandy loam
B15-SI	●●●			●	●●●	●●	●●●						●		●●●	●●	●●●	●●●	●	●●●	●●	17	4	silty clay loam
TV2-GZ	●●●	●●		●●	●●●				●●		●				●●	●●	●●	●●●	●●	●●	●	74	23	sandy loam
TV3-GZ	●●●	●●●		●●	●●●						●●		●●		●	●●	ND	ND	●●	●●●	●	73	37	silt loam
TV4-GZ	●●●	●●	●●	●●	●●●								●●		●●	●●	ND	●●●	●●	●●	●	68	18	loam
TV5-GZ	●●●	●●	●●	●	●●●								●	●	●●	●●	●●	●●●	●	●●●	●●	21	6	silty clay loam
TV12- SI	ND **															●●	●	●●●	●●●	●●	●	132	89	sandy loam
TV13-SI	●●●	●●	●●	●	●●				●●						●	●●	●●	●●	●●●	●●	●	149	99	sandy loam

Symbols - Relative Levels

High	●●●	major (primary mineral)***	>30k ppm	>10%	>50%
Moderate	●●	minor (secondary mineral)***	10k-30k ppm	2-10%	25-50%
Low	●	trace (low abundance)***	<10k ppm	<2%	<25%

*Carbonates
** No data: sample of insufficient size for XRD
***Relative amounts of mineral abundance:

Table 13. Summary of analytical results and characterization

Analysis	Bulk Dust Samples	Tactical Vehicle Samples	Overall Summary
Sample Strategy	• Sample a variety of geologic settings in Iraq likely to serve as dust source areas	• Sample dust that has accumulated in tactical vehicles operating in Iraq	• Bulk samples provide information about source • Tactical vehicle samples provide information about dust accumulating on and in military equipment
Major Cations	• Variable composition • Abundant Ca and Mg • $SiO_2 < 80\%$	• Variable composition • Abundant Ca and Mg • $SiO_2 < 80\%$	• Variable composition • Bulk and tactical vehicle samples similar
Mineralogy	• Quartz, plagioclase, feldspars common • Calcite common, dolomite infequent • Halite infrequent • Clay minerals: illite, palygorsite, saponite, kaolinite, montmorillonite	• Quartz, plagioclase, feldspars common • Calcite common, dolomite infequent • Halite infrequent • Clay minerals: illite, chlorite, saponite, kaolinite, montmorillonite	• Variable composition • Muscovite, chlorite, and kaolinite, most common • Bulk and tactical vehicle samples similar
Anions	• SO4- in all samples • Cl- abundant in 2 samples	• SO4- in all samples • Cl- abundant in 1 sample	• Sulfate common, Chloride infrequent • Bulk and tactical vehicle samples similar
Salt/Carbonate	• Carbonate in all samples • Soluble salt present in most samples	• Carbonate in all samples • Soluble salt present in most samples	• Soluble salts (e,g, NaCl, CaSO4) common • Tactical vehicle samples have a greater concentration of carbonate
Particle-size distribution	• Highly variable sand, silt, and clay content • Highly variable mean particle diameter • Distribution reflects environmental setting: sand dune, reg soils, intertidal, pond/marsh.	• Slightly variable sand, silt, and clay content • Slightly variable mean particle diameter • Distribution reflects trapping by vehicle	• Silt- and clay-size particles common • Tactical s vehicle samples greater clay and silt content and smaller mean particle size
Dust and Gun Oil	• Strong increase in coarse-silt and fine sand (~50-200 microns)	• Strong to moderate increase in coarse-silt and fine sand (~50-200 microns).	• Flocculation of dust in oil – increasing average size of dust particles. • All three oils tested resulted in flocculation.

RECOMMENDATIONS

Given the importance of Iraqi dust in its potential to impact military equipment and operations, several areas require further investigation. These include the following:

(1) Continue analysis of the chemical properties of Iraqi dust to evaluate potential for corrosion and related impacts to military equipment. Further dust analysis should focus on the size fraction <100 μm because this typifies dust and is the size fraction most likely to impact military equipment. Additional analysis should include detailed XRD of the fine-silt and clay fraction, examination of surface reactivity of dust particles, and evaluation of dust-induced corrosion on weapon metals.

(2) Consider critical and important desert environmental parameters to design tests that reflect real-world conditions—especially conditions most likely to compromise use of critical equipment in harsh desert environments. Previous work by King et al. (1999, 2004) demonstrated that each type of equipment test has a unique set of environmental conditions that are critical to the success of that test.

(3) Conduct visual verification of dust flocculation in gun lubricants through microscopy. Application of digital microscope technology (using an overlaid, scaled grid) would allow further verification of mean particle diameters within the oil matrix.

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APPENDIX A: SAMPLING STRATEGY FOR DUST IN IRAQ

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Sampling Strategy for Dust in Iraq
1/20/04
PREPARED BY:
Dr. Eric McDonald

Desert Research Institute
Center for Arid Lands Environmental Management

SAMPLING STRATEGY FOR DUST IN IRAQ

Classification of potential role of dust in limiting performance of the M16 can be separated into three types of samples. Strategy is to collect soil areas likely to be a major contributor to regional aerosols (dust) and to collect samples from areas in close proximity to where weapon problems are occurring:

(1) REGIONAL SOIL SAMPLES: Dust emission from soils is likely to be a major contributor to dust. Samples are needed from key regions (especially if problem is prevalent to certain areas). Samples are needed from soils likely to produce dust:

REG SOILS: soils that have a gravel lag (desert pavement) overlying a silt-rich subsoil horizon. These soils are common on older landforms and can emit dust when the surface is highly disturbed.

FLOODPLAIN AND RIVER BOTTOM SOILS: soils located along broad, major river valleys, especially areas the used for agriculture and are likely to emit dust during wind storms. Soils that are rich –in silt and clay are best candidates.

SOIL FROM PLAYAS, LAKE BASINS, SEBKAS: Samples from topographic lows where silt- and clay-rich sediment accumulates.

EOLIAN DEPOSITS/SAND SHEETS: Samples from eolian mantles that are likely to produce dust when disturbed or under wind storms.

(2) SAMPLES FROM TACTICAL VEHICLES: Moving vehicles will serve as moving dust traps. Samples should be collected from vehicles by scrapping dust

off of interior or exterior surfaces. Key is to locate samples from vehicles where weapons are likely to be in prolonged contact. Also, vehicles sampled should be in areas where weapons problems occur most frequently.

(3) SAMPLES FROM INOPERATIVE WEAPONS: Samples should be collected, if possible, from weapons that have jammed. Samples could simple consists of all material (i.e. lubricating oil, debris, etc.) that can be scrapped from the weapon.

NUMBER OF SAMPLES: More is better than few. Suggested minimum sample numbers (if possible) Regional soils samples (15), Vehicle samples (5), Weapon samples (3).

SAMPLE STORAGE: All samples should be sampled into bottles or heavy plastic bags and sealed to prevent contamination. Sample sites should include description of main geologic and landform attributes, location, and reason for sampling (i.e. soils rich in silt, dust-storm producing area, etc.).

SAMPLE SHIPMENT: DRI maintains a USDA permit for receiving soil samples from areas outside of the US. Samples must be double-bagged and shipped in sturdy containers (heavy cardboard, or and heavy plastic box). A copy of DRI's permit must be included both inside each box AND in an accessible/visible envelope on the exterior of each box. We routinely ship samples through US Customs via FedEx. Address for shipping samples is

Dr. Eric McDonald
Soil Characterization Laboratory
Desert Research Institute
2215 Raggio Parkway.
Reno, NV 89512

(775) 673-7300 (Main Office)
(775) 673-7430 (Soil Lab)

APPENDIX B
TRIP REPORT: COLLECTION OF SOIL SAMPLES IN IRAQ

APPENDIX B TRIP REPORT: COLLECTION OF SOIL SAMPLES IN IRAQ

6 May 2004

ERDC
3909 Halls Ferry Road
Vicksburg, MS 39180

Trip Report:
Collection of soil samples in Iraq, March and April 2004

Prepared by
Julie Kelley
Engineering Geology and Geophysics Branch
Geotechnical Laboratory

CEEERD-GG **6 May 2004**

Memorandum for Record

Subject: Collection of some soil samples in Iraq.

Background

The M16 rifle, manufactured by Colt, has been the standard Army assault rifle for nearly 40 years. It has proven to be a fairly reliable weapon, with continued field and laboratory testing, resulting in some modification. The latest version, the M16A2, was the outcome of a product improvement program completed by the Army in 1978.

A major complaint of weapon performance relates to problems with jamming attributed to dust and sand. Some past modifications directly addressed this issue. However, reports from the field in Iraq were brought to the attention of employees at Yuma Proving Ground in Arizona. Recent complaints indicate that the problem with jamming is still present and particularly apparent in that arid environment.

Past research for use of the weapon in desert conditions included testing with soil samples of standard grain-size. However, an examination of the unique properties of Iraqi soil has never been done and could provide specific information about the operation of the weapon in that setting.

Graham Stullenbarger, of the US Army Yuma Proving Ground discussed with Dr. Eric McDonald of the University of Nevada's Desert Research Institute the need for a research program to determine what characteristics of the dust in Iraq contribute to jamming in the M16A2. In a later discussion between Dr. McDonald and Dr. Russell Harmon of the Army Research Office (ARO), it was learned that the Engineering Research and Development Center (ERDC) had a geologist in Iraq on a temporary duty assignment. Dr. Eric McDonald contacted Dr. Lillian Wakeley, Branch Chief of the Engineering Geology and Geophysics Branch of the Geology and Structures Lab at the Engineering Research and Development Center (ERDC) in Vicksburg, MS, and learned that Julie Kelley, who was already in Iraq, could collect the samples.

Sample Collection

Julie Kelley, a research geologist from ERDC, was working from December, 2003 to April 2004 as a GIS specialist for Task Force Restore Iraqi Oil in Baghdad, Iraq. She collected the soil samples for the study using the sampling plan provided by Dr. Eric McDonald of DRI as a guide. Representative soil types were taken from sites that would most likely be contributing to the formation of dust. Locations for collection were chosen in Baghdad, within the Green Zone, where many of the tactical vehicles in use travel throughout the central part of the country. Also, soil samples were taken in the southern part of Iraq near Basrah, where a good representation of desert landforms can be located. All samples were taken from tactical vehicles or from the shallow surface in regional soil settings. The samples from the vehicles were collected with a metal spoon or a clean toothbrush and placed in hard plastic vials. The surface soil samples were collected with a plastic spoon and were placed in quart sized zip lock plastic bags. One surface soil sample consisted of one quart bag unless otherwise stated. The plastic bags were double-bagged. The samples were and boxed and shipped to DRI on Thursday, April 8, 2004 on their permit. The following is a description of the sample collection:

Saturday, 27 March 2004

1. (B1-GZ)) River Bottom - Tigris River sediment after flood. During the previous two weeks, a paved area in the Green Zone in Baghdad adjacent to the shoreline was flooded with at least two and a half feet of water during a flood of the Tigris River. A fine layer (one-half inch in depth) of silt and some sand remained in place when the water receded (Figures 1 and 2). This soil is representative of river bottom sediment and contains fine-grained sand, silt and some clay. Upon drying, polygonal cracks develop in the soil (Figure 3).

Sunday, 4 April 2004

2. (TV2-GZ) Tactical Vehicle – Humvee. Samples were taken from driver's side floor and from the wheel well. Very little soil was present inside the vehicle for sampling. This vehicle is used by the security personnel and does not usually travel far from the immediate area. Soil obtained here has most likely collected over time and has not been disturbed much. During the previous months, the vehicle has been parked adjacent to the Tigris River shoreline. The sediment contained some fine-grained sand and silt (Figure 4).

3. (TV3-GZ) Tactical Vehicle – Humvee. Samples dusted from dash, inside door and top of radio only. This vehicle travels daily outside of the Green Zone. Very fine grained silt.

4. (TV4-GZ) Tactical Vehicle – Humvee. Samples taken from wheel wells. Fine grained sand and silt. Very little soil inside vehicle. Discussion with a soldier results in a look at a very fine layer of dust that had developed inside his weapon (Figure 5).. He reported that the dust layer had built up after only a few hours on duty. The dust coated the entire inside of the chamber and was so fine that individual sand grains were not visible. He works both inside and outside the Green Zone and reports that he travels quite a bit. He says that he does not usually use a lubricant and notes that oils would only add to dust buildup. He cleans his weapon every day and does not have problems with weapon jams.

5. (TV5-GZ) Tactical Vehicle – Humvee. Samples taken from wheel wells. This vehicle

travels daily outside the Green Zone. Very little soil inside the vehicle for sampling. Fine grained sand and silt.

Monday, 5 April 2004

Travel to and arrival at Basrah International Airport and British military base. Task Force RIO (Restore Iraqi Oil) South Area Office is also at this location. Plan to spend the next three days collecting soil samples from the surrounding area at secure construction sites and camps.

During travel, the plane was delayed due to increasing security concerns. Attacks toward coalition forces have increased during the previous week. Travel is discouraged and a decision is made in the South Area Office to avoid all travel for the next 24 hours.

Tuesday, 6 April 2004

We are unable to leave the South Area Office due to security concerns.

Interview with Reservist, Sgt. Derek Lincoln, from the 182nd out of Tulsa, OK:

Sgt. Derek Lincoln states that the upper receiver of the M16, where the bolt carrier has free space to move, is a very tight confined space. Applying excessive amounts of CLP (lubricant) in the desert environment will only lead to jamming. If CLP (or another light oil) is used, only a thin coat should be applied. The weapon has to be cleaned daily to ensure proper functioning in this environment.

He notes that after many years of experience with the M16, carbon residue buildup inside the weapon is a common problem in any environment. Trying to add lubricant would cause the carbon to solidify and produce a gumming effect. This compounds the problems with the fine, silty sand in the desert and should probably also be addressed in our research.

Wednesday, 7 April 2004

A car bomb has been discovered and detonated at the front gate of the camp without incident. A scheduled trip to three collecting locations near the South Area Office is allowed today.

6. (B6-SI) Floodplain and River Bottom. The sampling location is in a broad, flat area adjacent to the shore of the Shatt Al Arab River. Tidal influence from the Persian Gulf affects this part of the river. The sample contains pebbly sand, silt and some clay. As the soil dries, polygonal cracking is present and in some places, a crust of evaporates has developed (Figure 6).

7. (B7-SI) Regional Soils. Area with a gravel lag overlying silty soil sampled. Caliche present in soil. Soil is poorly sorted with pebbly sand and silt (Figure 7).

8. (B8-SI) Regional Soils. A second area is sampled that has a gravel lag overlying silty soil. Caliche is also present here. Soil is also poorly sorted with pebbly sand and silt.

9. (B9-SI) Floodplain and River Bottom. Pebbly sand, silt and clay with a crust of evaporites. Soil still wet (Figure 8).

Travel by car to second collecting location.

10. (B10-SI) Playa. Soil taken from surface of topographic low area that contains a dried up playa lake. Fine grained silt and clay. Polygonal cracking (Figure 9).

11. (B11-SI) Eolian. Soil taken from area of rippled windblown sand dunes. Sand is medium grained and well-sorted.

12. (TV12- SI) Tactical Vehicle – Humvee. Very little soil inside vehicle for sampling. Sample taken from wheel well. Fine grained sand, silt and clay.

13. (TV13-SI) Tactical Vehicle – Truck. Samples taken from outside of vehicle from wheel well and door.

Travel by car to third collecting location.

14. (B14-SI) Regional soils. Broad, flat area that is located several miles inland from the Shatt Al Arab River shoreline. Four samples taken in close proximity from areas containing gravel lag overlying silty soil.

Travel by car back to camp at the Basrah International Airport.

Thursday, 8 April 2004

15. (B15-SI) Lake Basin – Basrah International Airport. Samples taken in topographic low that still has some standing water. This are was originally part of the interior marshland and has been fairly well drained. Where the soil has dried, polygonal cracking is present as well as a crust of evaporites. Silty soil with some clay.

Decision is made to travel by car today (one day early) to Kuwait due to security concerns. Samples are prepared for mailing and then mailed at Camp Bucca (US Army camp) on the way to Kuwait.

Proposed Path Forward

The initial phase of sampling has been completed and the samples have been submitted for analysis. Samples were taken from tactical vehicles and surface areas only. No samples were collected from weapons as was requested by the dust sampling strategy. Julie Kelley has some contacts that may be able to arrange this. Further discussion is needed concerning this.

Plan to meet with Dr. Eric McDonald later to discuss the results of soil analysis. Further description of sampling locations, including a discussion of the geology of the areas combined with field observations will most likely be necessary. A GIS display of sampling locations will also follow.

Points of Contact:

ERDC
Julie Kelley, Research Geologist Engineering Research and Development Center
Tel: 601/634-3551
julie.r.kelley@erdc.usace.army.mil

Dr. Lillian Wakeley, Branch Chief Engineering
Geology and Geophysics Branch Engineering
Research and Development Center
Tel: 601/634-3215
lillian.d.wakeley@erdc.usace.army.mil

DRI
Dr. Eric McDonald Earth and Ecosystem Sciences Desert Research Institute
Tel: 775/673-7320
emcdonal@dri.edu

ARO
Dr. Russell S. Harmon Engineering
and Environmental Sciences Div
(AMSRI-RO-EN) Army Research
Office Tel: 919/549-4326
harmon@aro-emhl.army.mil

YPG
Graham Stullenbarger Natural Environmental Test Office Directorate of Command
Technology US Army Yuma Proving Ground Tel: 928/328-6679
Graham.stullenbarger@yuma.army.mil

Figure 1. Flood of Tigris River within Green Zone in Baghdad, Iraq.

Figure 2. Flood begins to recede and leaves sediment behind.

Figure 3. Polygonal cracking in Tigris River sediment.

Figure 4. Dust is collected from the interior of a humvee.

Figure 5. Very fine layer of dust has built up inside weapon after only a few hours.

Figure 6. Floodplain and river bottom sediment in Shatt Al Arab River.

Figure 7. Soil with a gravel lag (desert pavement) and caliche.

Figure 8. Evaporite crust developing on some floodplain soil.

Figure 9. Polygonal cracking in soil from small playa lake.

APPENDIX C: SATURN DIGISIZER 5200 PARAMETERS AND OUTPUT FILES

APPENDIX C: SATURN DIGISIZER 5200 PARAMETERS AND OUTPUT FILES

Software: Micromeritics Instrument Corporation, Saturn DigiSizer Version 1.09.

Table 1: Analysis conditions and material properties for Iraqi samples in water, and gun lubricants

Matrix	RI: Liquid[1]	RI: Soil Real	RI: Soil Imaginary	Sonciation Intensity (%)	Sonciation Time (s)	Sonciation Recirc. (s)	Obs. (%)	Flow Rate	Viscosity[2] (CP)	Density (g/ml)
De-aerated water	1.311	1.550	0.100	100	250	250	35-45	16	0.798	0.996
CLP1	1.459	1.550	0.100	75	250	250	35-45	2	60	0.915
Strike Hold	1.475	1.550	0.100	75	250	250	35-45	3	20	0.915
Militec	1.475	1.550	0.100	75	250	250	35-45	4	60	0.915

[1]Analyzed by Micromeretics

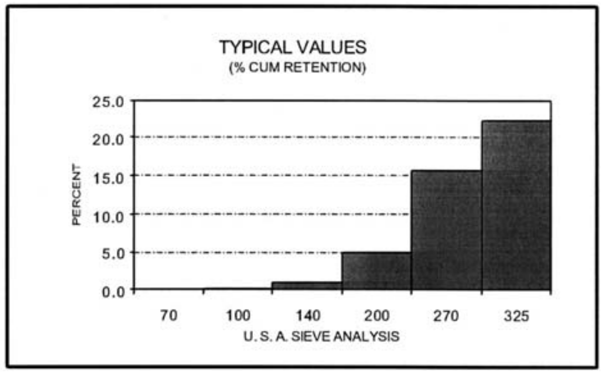
[2]Adjusted to achieve proper flow rate

APPENDIX D: GROUND SILICA PRODUCT SHEET

APPENDIX D: GROUND SILICA PRODUCT SHEET: SILICA-RICH SAMPLE USED FOR SMALL-ARMS TESTING

U.S. SILICA®
Sands of Time

PRODUCT DATA



SIL-CO-SIL® 106

GROUND SILICA

PLANT: MILL CREEK, OKLAHOMA

USA STD SIEVE SIZE		TYPICAL VALUES		
		% RETAINED		% PASSING
MESH	MILLIMETERS	INDIVIDUAL	CUMULATIVE	CUMULATIVE
70	0.212	0.0	0.0	100.0
100	0.150	0.1	0.1	99.9
140	0.106	0.9	1.0	99.0
200	0.075	3.9	4.9	95.1
270	0.053	10.7	15.6	84.4
325	0.045	6.7	22.3	77.7

TYPICAL PHYSICAL PROPERTIES

HARDNESS (Mohs) 7
MELTING POINT (Degrees F) 3100
MINERAL .... QUARTZ
pH 7

REFLECTANCE (%) 89.4
YELLOWNESS INDEX 3.63
SPECIFIC GRAVITY 2.65

TYPICAL CHEMICAL ANALYSIS, %

SiO_2 (Silicon Dioxide)................................ .... 99.7
Fe_2O_3 (Iron Oxide)............................... .... 0.016
Al_2O_3 (Aluminum Oxide)................................ 0.14
TiO_2 (Titanium Dioxide)............................... <0.01
CaO (Calcium Oxide) .... <0.01

MgO (Magnesium Oxide)............................... .... <0.01
Na_2O (Sodium Oxide)............................... .... <0.01
K_2O (Potassium Oxide) 0.02
LOI (Loss On Ignition) 0.1

May 29, 1998

DISCLAIMER: The information set forth in this Product Data Sheet represents typical properties of the product described; the information and the typical values are not specifications. U.S. Silica Company makes no represen tation or warranty concerning the Products, expressed or implied, by this Product Data Sheet.

WARNING: The product contains crystalline silica - quartz, which can cause silicosis (an occupational lung disease) and lung cancer. **For detailed information o n the potential health effect of crystalline silica - quartz, see the U.S. Silica Company Material Safety Data Sheet.**

—From U.S. Silica Company